

Ultrafast all-optical switching of telecom single photons

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Abstract: Low-loss, ultrafast photon routing is an enabling technology for optical quantum information processing. We demonstrate a 20 GHz, all-optical switch for 1590-nm photons from a heralded single-photon source, achieving a signal-to-noise ratio of 140:1. © 2022 The Author(s)

1. Introduction

Low-loss, rapid switching solutions are vital to the development of several applications in photonic quantum information science. Fast switches form an integral component of multiplexing schemes that enable quantum resources such as single-photon generation [1], long-distance entanglement swapping for quantum communication [2], and exotic quantum state creation for quantum metrology [3].

The Pockels effect in bulk, electro-optic crystals is a relatively low-loss solution, but suffers from slow switching rates (~ 10 MHz) and a high voltage demand of several kilovolts. While on-chip electro-optic modulators address the high voltage problem and offer the benefit of scalability, these typically suffer from high insertion losses. A simple, yet elegant approach to attain both low losses (< 0.6 dB) [4] and up to \sim THz switching rates [5] is to utilize cross phase modulation in an optical fiber. A pump pulse induces birefringence in the fiber and a co-propagating signal pulse (of a different wavelength) experiences a nonlinear phase shift as it “walks over” the pump pulse, due to their different group velocities in the fiber. This nonlinear phase shift can be used to make a polarization-based Optical Kerr Shutter (OKS) [5] or a polarization-insensitive 2×2 nonlinear optical loop mirror switch [6]. Here, we present an OKS for telecom band (1590 nm) single photons, using a 1042-nm pump pulse.

2. Methods and results

Figure 1 shows a schematic of our experimental setup. A 1042-nm pulse is doubled to 521 nm, and is used to pump a downconversion crystal creating trigger photons at 777 nm and heralded single photons at 1590 nm. These are spatially combined with the leftover 1042-nm pulses from the second harmonic generation process by using a dichroic mirror. Prism and filters serve to reject the pump pulses and unwanted in-band noise that might arise from competing processes in the fiber, such as fluorescence and Raman scattering. The signal pulses are measured in coincidence with the 777-nm idler photons using high-efficiency ($> 90\%$) superconducting nanowire single photon detectors (SNSPDs), such that the switched and un-switched pulses arrive in different coincidence time-bins.

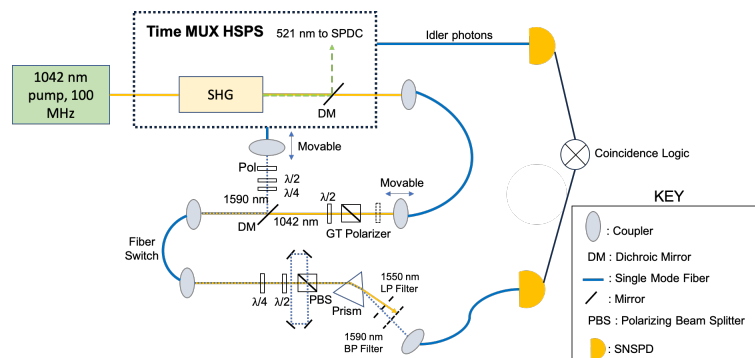


Figure 1. Switch schematic: the polarization optics are set so that the PBS transmits (reflects) the switched (unswitched) signal.

It is crucial that the two pulses are timed correctly so that they completely walk through each other in the fiber, whereby the signal experiences a near-uniform phase shift across its temporal profile; in practice, this can be achieved by choosing a fiber long enough to allow a complete walk-off. Currently, we are using 22 m of SMF28E as our switch fiber. In order to estimate the walk-off, we attenuate the pump and measure the output of the switch fiber directly with the SNSPDs (bypassing the filtration system), in correlation with the idler photons. By adding a known length of fiber and repeating the measurement, we compared the difference between the pulses' centroids in both cases to estimate that the walk-off between the two wavelengths is 1.26 ± 0.09 ps/m, as shown in Fig. 2.

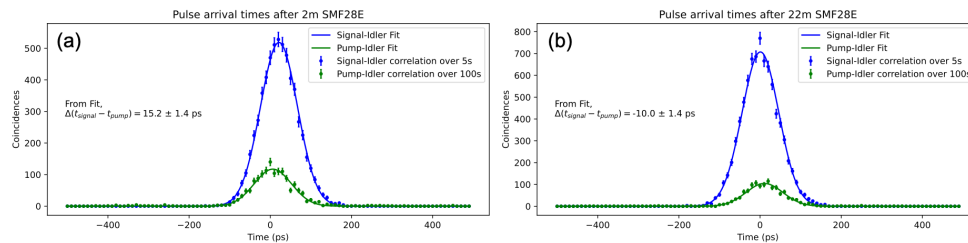


Figure 2. Estimating walk-off by measuring pulse arrival times (centroids from Gaussian fits) in correlation with the idler photons by using (a) 2 m and (b) 22 m SMF28E fiber.

To characterize the switching response of our OKS, for a given pump power, we adjust the the two pulses' arrival times at the switch fiber. When the positions of the movable couplers are such that the two pulses can have maximum interaction time in the fiber, we successfully achieve maximum switching as shown in Fig. 3. The length of the switching window defines our switching time, and its reciprocal determines our switching rate, ~ 20 GHz.

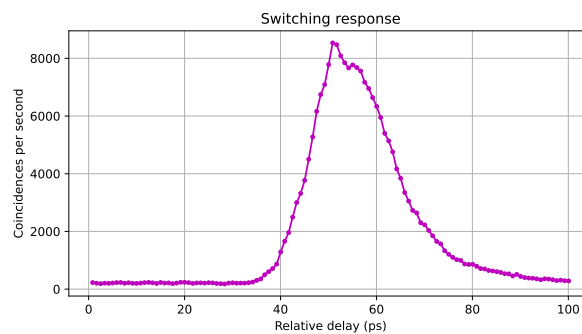


Figure 3. Characteristic switch response as the relative delay between the pump and signal is varied.

3. Conclusion and Outlook

We note the the efficiency of our system seems to be saturating at $\sim 24\%$, when we are supplying ~ 130 mW of pump power to the fiber. At this efficiency, we have a signal-to-noise ratio of $\sim 140:1$. Our hypothesis is that wavelength-dependent polarization scrambling is negatively impacting the switching process. Methods to mitigate this are under investigation. In conclusion, we have demonstrated ultrafast, all-optical switching of telecom-band single photons and will continue to develop the switch to achieve higher metrics.

References

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