# A cascaded interface to connect quantum memory, quantum computing and quantum transmission frequencies

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**Abstract:** We implement a cascaded interface connecting three essential frequencies for quantum communications including 1540 nm for long-distance transmission, 895 nm for Cesium quantum memory and 369 nm for Ytterbium ion quantum computing applications. 
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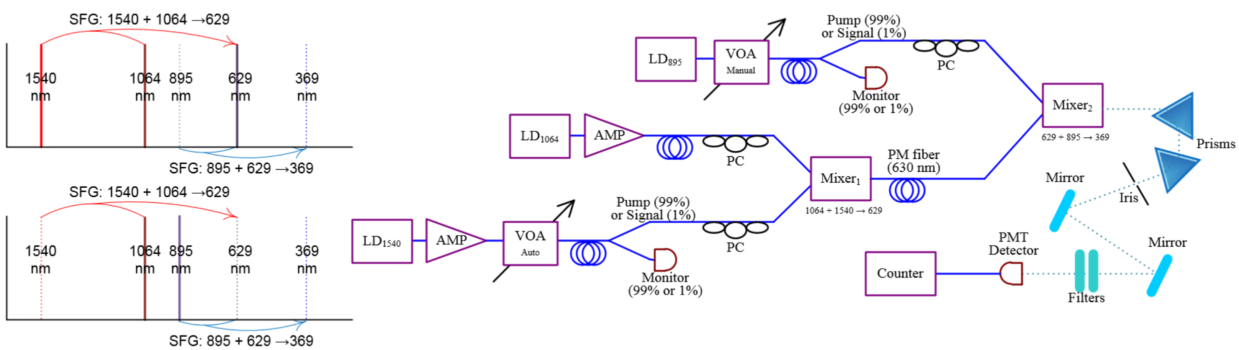
## 1. Introduction

Future distributed quantum computing networks will require different technologies and materials to implement particular processes such as the quantum transmission, storage and computation. Typically, the most suitable material or technology varies from process to process and with it, the particular wavelength at which that process can be implemented most optimally. Quantum interfacing is therefore an essential link to enable these different processes at different wavelengths to be combined in a single network. In particular, the wavelength of 1540 nm is suitable for the long-distance transmission of quantum state encoded single photons in standard telecom optical fibers. The wavelength of 895 nm can be used for quantum state storage and quantum memory based on Cesium atoms [1]. The wavelength of 369 nm can be used for quantum computing applications based on Ytterbium trapped-ions [2]. In this paper, we introduce a cascaded interface that connects all three of the wavelengths required for these processes in a single experimental set-up. Single photons form either a Cesium based quantum memory device at 895 nm or transmitting through a fiber at 1540 nm can be selectively converted to 369 nm for use in quantum computing. The cascaded quantum frequency conversion mechanisms are illustrated in Fig. 1(a). The experimental set-up is shown in Fig. 1(b) and described in the text.

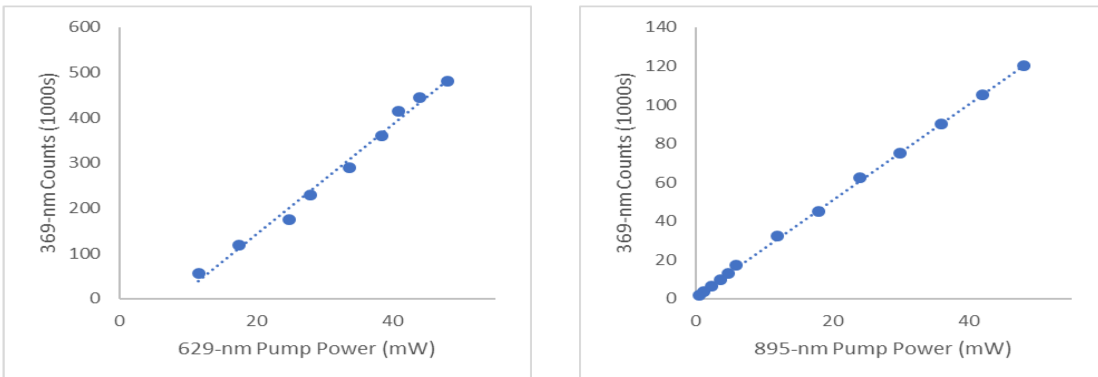



(a) (b)

Fig. 1. (a) Illustration of the frequency conversion processes. Upper: signal at 895 nm converted to 369 nm with pump at 629 nm generated from a strong 1540 nm and 1064 nm pre-pumps. Lower: signal at 1540 nm converted to 629 nm and subsequently to 369 nm with a pump at 895 nm. SFG: sum-frequency-generation. (b) Schematic of the cascaded interface experimental set-up. $LD_{wavelength}$: laser at specified wavelength; AMP: amplifier; VOA: variable optical attenuator (manual or automatic); PC: polarization control; PMT: photomultiplier tube.

The mixers are based on sum-frequency-generation (SFG). The first mixer (SFG: 1540 nm + 1064 nm → 629 nm) has a normalized conversion efficiency of approximately 70%/W. The second mixer (SFG: 895 nm + 629 nm → 369 nm) has a normalized conversion efficiency of approximately 10%/W. Strong 1540 nm and 1064 nm pumps can be combined in the first conversion device to form a strong pump at 629 nm which can then be used to convert a single photon signal at 895 nm to 369 nm in the second conversion device. On the other hand, a single-photon signal at 1540 nm can be combined with a strong pump at 1064 nm to be converted to the intermediate wavelength of 629 nm in the first conversion device. These newly generated 629 nm single photons can subsequently be combined with the strong pump at 895 nm and converted to 369 nm in a second conversion device. In each case, the single photon signals are provided by a greatly attenuated signal laser. After the second mixer, the free-space output is separated from the residual pump light using two prims, an iris and a 369 nm filter. The prism legs are anti-reflection coated at 369 nm. The filter has approximately 30% transmission from 365 nm to 375 nm and provides over 80 dB attenuation otherwise. The signal is then guided into a photomultiplier tube whose detection efficiency at 369 nm is approximately 2% and whose dark-count rate is less than 200 counts per second (cps). The electrical output from the PMT goes directly to a counter. Both of these processes have been implemented and the results reported here are limited only by the amount of pump power available from our equipment.

## 2. Results and Discussion




(a) (b)

Fig. 2. Measured counts as a function of pump power for: (a) a 0.0035 μW 895 nm input to $Mixer_1$. (b) a 0.005 μW 1550 nm input to $Mixer_2$. The detection efficiency (detailed in the text) is primarily limited by the efficiency of the detector and the maximum pump power available for each conversion process. The continuing linear increase in detection efficiency indicates that a higher pump power will increase the overall conversion rate of the cascaded interface.

The maximum pump power available at 629 nm (from our 1064 nm and 1550 nm amplifiers) is 50 mW which gives a total conversion efficiency of the second mixer of approximately 0.5%. The total detection rate of the system is therefore approximately $3x10^{-5}$ including the filter and detector. We confirmed this detection rate by using a greatly attenuated laser at 895 nm as an input to this mixer. The detection efficiency of the system remains linearly increasing with the pump power beyond our maximum available pump (see Fig. 2(a)). A higher pump will lead to a higher conversion efficiency. We additionally performed the cascaded conversion of low-light from 1540 nm to 629 nm to 369 nm. The maximum power available from the 1064 nm laser amplifier (120 mW) gives a conversion efficiency of approximately 9% in the first mixer. A maximum pump power of approximately 50 mW at 895 nm was provided to the second mixer. The total conversion and detection rate of this scheme is therefore estimated to be $2.7x10^{-6}$. Again, we confirmed this detection rate by using a greatly attenuated 1550 nm laser as the input to the system. The efficiency remains linearly increasing with pump power (Fig. 2 (b)) and more pump power will result in greater overall conversion efficiencies.

It should be noted that the noise counts from the strong pump powers are not noticeable. Once any of the inputs required for the generation of 369 nm photons is turned off and all the other input are at their maximum available powers, the dark count rate reverts to under 200 cps – the same as when everything is turned off.

This cascaded interface will be very useful for hybrid long-distance fiber networks for distributed quantum computing that use Cesium-based quantum memories and Ytterbium-based quantum computers.

## 3. References

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