Multi-channel entanglement distribution using spatial multiplexing from
four-wave mixing in atomic vapor

Travis Horrom¹, Prasoon Gupta¹, Brian E. Anderson¹, Ryan Glasser², Paul D. Lett¹

1. Joint Quantum Institute: National Institute of Standards and Technology and University of Maryland, Gaithersburg, MD 20899 USA.
2. Department of Physics and Engineering Physics, Tulane University, 6400 Freret Street, New Orleans, Louisiana 70118 USA.

Quantum communications and cryptography requires resources to encode information and to share it among multiple users in quantum networks. Secret sharing is a multi-user protocol which allows a sender to transmit information to several receivers in such a way that the receivers must work together to access the information, providing a higher level of protection for sensitive information [1]. By transmitting information along quantum channels, the security of the transmission can be ensured via quantum key distribution [2]. In this proof-of-principle experimental work, we demonstrate a secret sharing protocol by making use of spatial multiplexing of entangled twin beams of light. We show that four-wave mixing (4WM) in hot Rb atoms can produce an entangled light state whose multi-mode nature allows for the use of independent pairs of correlated spatial modes to be used as multiple quantum channels for key distribution simultaneously. We also find these vacuum twin beams, which are generated from spontaneous emission, to be a good source of correlated random numbers which can be used in the key distribution.

The basic experimental design is shown in Fig. 1. A strong pump beam is sent through a hot vapor of $^{85}$Rb which produces a multi-spatial mode cone of correlated light subject to the phase-matching conditions in the medium [3]. From this cone we select three pairs of probe and conjugate modes and detect the quadrature noise of each mode with homodyne detectors. Each probe mode shows independent random quantum noise, but is correlated to its partner conjugate mode such that a joint measurement on the probe-conjugate pair displays two-mode vacuum squeezing.

In the secret sharing scheme, Alice measures the time-dependent quadrature noise on the three probe modes with three homodyne detectors, then discretizes and bins the signals to create bit streams which are added together to form a single secret key. The correlated conjugate modes are measured by the receivers Bob, Charlie, and Diana, each of whom creates a bit stream in the same way, and Alice’s key can only be recovered if the receivers classically combine their bit streams. Each receiver alone holds no information about the secret key.

To demonstrate this scheme, we test the randomness of each bit stream created with statistical tests. We then measure the bit-wise agreement between pairs of bit streams used, both to quantify the correlations among Alice’s probe modes and the receivers conjugate modes as well as to verify the independence of unpaired probe/conjugate modes. At the same time, we perform joint measurements to observe the two-mode squeezing of the correlated vacuum beams. By using quantum-correlated states, the security of the key distribution could be verified in principle. This is the first demonstration of spatial multiplexing for entanglement distribution, and highlights the possibility for using 4WM in atomic vapor as a resource in quantum communications and cryptography protocols. This method should also be scalable to many more users; similar states have been demonstrated containing up to 100 independent spatial modes.

References