Continuous Variable Entanglement Distillation by means of Noiseless Linear Amplification.

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Entanglement is essential for wide range of quantum technologies. Unfortunately quantum entanglement is vulnerable to losses and noise and degrade fast with propagation distance, but entanglement distillation [1] allows to struggle with its inevitable degradation. Essence of entanglement distillation is to select from a large set of weakly entangled states smaller subset of quantum states which have stronger level of entanglement. The main entanglement resource in continuous variable (CV) domain is two-mode squeezed vacuum state (TMSV) an approximation of Einstein-Podolsy-Rosen state [2]. TMSV state is a basis for many quantum technologies such as: continuous-variable teleportation [3] or quantum repeaters [4].

In this paper we present experimental realisation of CV entanglement distillation (ED) protocol by means of noiseless linear amplification (NLA) [5]. Our protocol is based on technique known as quantum catalysis [6] and, in contrast to previous implementations of CV ED [7], entanglement amplification achievable by our technique is not limited by factor two, so it can be used in practical CV quantum repeaters.

In the case of weak squeezing initial TMSV state can be written as:

$$|TMSV\rangle \approx |0,0\rangle - \gamma|1,1\rangle, \tag{1}$$

where $\gamma \ll 1$. This state propagates through a lossy channel with amplitude transmissivity τ. Then, to distill the entanglement, we bring it into interference on a low-reflectivity beam splitter with an ancillary single photon [8]. The distillation event is heralded by detecting a single photon in one of the outputs of the beam splitter. As a result, the state becomes in the first order of r, γ and τ:

$$r|0,0\rangle - \gamma\tau|1,1\rangle, \tag{2}$$

We see that, although the single-photon component is degraded by the loss, this is compensated by the reduction of the vacuum part due to noiseless amplification. Thus, the final entanglement depends only on the ratio $\frac{\gamma\tau}{r}$. And at gain level $g = (\gamma\tau)^{-1}$ the distilled state reaches initial level of entanglement.

In the experiment, we start with a TMSV with the difference position quadrature variance of $\langle (X_1 - X_2)^2 \rangle = 0.86 \pm 0.01$. Then we introduce a one-sided 95% loss. After the amplification, the difference quadrature variance returns to the initial level: $\langle (X_1 - X_2)^2 \rangle = 0.87 \pm 0.01$ [Fig. 1(a)]. This result corresponds to the amplification by factor 10 and that is much more than previously obtained results [7]. In [Fig. 1(b)] we calculate the Duan [9] inseparability criterion for CV systems and show that the amount of the recovered entanglement is greater than that even a perfect EPR state would exhibit after a one-sided 95% loss.

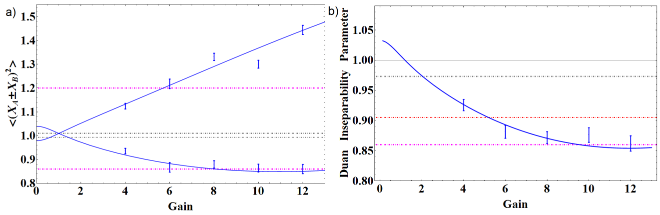

FIG. 1. Experimental results. a) Two-mode squeezing as a function of the NLA gain. The vertical axis is scaled in the units of shot noise. The upper set of points correspond to the position quadrature sum (antisqueezed), lower to the difference (squeezed). The purple lines corresponds to the initial state squeezing and antisqueezing; gray line to the state after one-sided 95% loss, where the squeezed and antisqueezed variances are degraded to 0.993 and 1.010, respectively. b) Duan inseparability parameter. The horizontal lines are as in (a); the red line corresponds to the inseparability parameter for a perfect EPR state that has experienced a one-sided 95% loss (total Duan variance equals 0.905).

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