Quantum noise eater for a single-photonic qubit

Miroslav Gavenda, Lucie Čelechovská, Miloslav Dušek, Radim Filip

Department of Optics, Faculty of Science, Palacky University,
17. listopadu 12, 771 46 Olomouc, Czech Republic

We propose quantum noise eater for a single photonic qubit and experimentally verify its performance for recovery of a superposition carried by a dual-rail photonic qubit. A coherent but randomly arriving photon penetrating into single rail of this system causes a change of its state, which results in an error in a subsequent quantum information processing. We theoretically prove and experimentally demonstrate a conditional full recovery of the superposition by the quantum noise eater.

Motivation

Qubit resource

- $[|0\rangle + \exp(i\varphi)\,|1\rangle]/\sqrt{2}$
- dual-rail enc:
  $|\Psi\rangle_{AB} = [|1,0\rangle_{AB} + \exp(i\varphi)\,|0,1\rangle_{AB}]/\sqrt{2}$
- Perfect resource for further quant inf processing
- Evaluation of the resource by visibility V
- $V = 1$

Trouble with coherent noise

- $a_B^\dagger|\Psi\rangle_{AB} =$
  $|\Psi'\rangle_{AB} = [|1,1\rangle_{AB} + \sqrt{2}\exp(i\varphi)\,|0,2\rangle_{AB}]/\sqrt{3}$
- state fully coherent
- may cause errors in further processing
- $V = \frac{2}{3}$

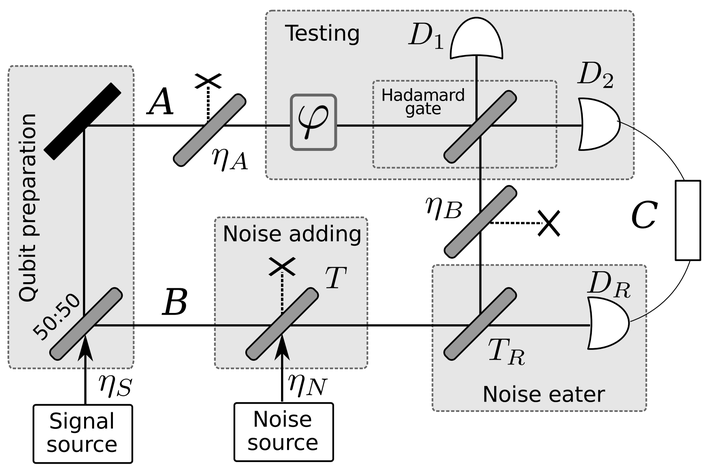
Noise eater technique

- Partial measurement of laser light
- Feedback controller with modulation

Qubit noise eater

- photon subtraction
- $a_B|\Psi'\rangle_{AB}$ ending up with state
- $|\Psi''\rangle_{AB} = [|1,0\rangle_{AB} + 2\exp(i\varphi)\,|0,1\rangle_{AB}]/\sqrt{5}$
- If mode "B" properly attenuated $V = 1$

Theory



Without noise eater

$$P = \frac{\eta_D}{4}\left(W_1 + W_2\cos\varphi\right),$$

$$W_1 = 2\,\eta_N\eta_B + \eta_S\eta_A + \eta_S\eta_N\eta_B T\eta_D\eta_A - 2\,\eta_N\eta_B T - \eta_S\eta_N{\eta_B}^2\eta_D T + \eta_S\eta_N\eta_B T - \eta_S\eta_N\eta_B\eta_D\eta_A + \eta_S\eta_N{\eta_B}^2T^2\eta_D$$

$$W_2 = 2\,\eta_S\eta_N{\eta_B}^{3/2}\eta_D\sqrt{T}\sqrt{\eta_A} - 2\,\eta_S\eta_N{\eta_B}^{3/2}T^{3/2}\eta_D\sqrt{\eta_A} - 2\,\eta_S\sqrt{T}\sqrt{\eta_A}\sqrt{\eta_B}$$

$$V = \frac{P_{\max} - P_{\min}}{P_{\max} + P_{\min}}$$

$$V = \frac{\eta_S T(\eta_B\eta_N T\eta_D - \eta_B\eta_N\eta_D + 1)}{\eta_B\eta_S\eta_N\eta_D T(T-1) + \eta_S T + \eta_N(1-T)}$$

$$\text{if } \eta_A = \eta_B T$$

$$V = \frac{2T + \eta_B\eta_S T(T-1)}{2 + \eta_B\eta_S T(T-1)}$$

$$\text{if } \eta_N \ll 1 \text{ and } \eta_S \ll 1$$

$$V = T$$

With noise eater

$$P_c(\varphi) = \tfrac{1}{4}\eta_S\eta_N T_R\eta_D\eta_R(1-T)(\eta_A + 4\eta_B T(1-T_R) - 4\cos(\varphi)\sqrt{\eta_A\eta_B T(1-T_R)}).$$

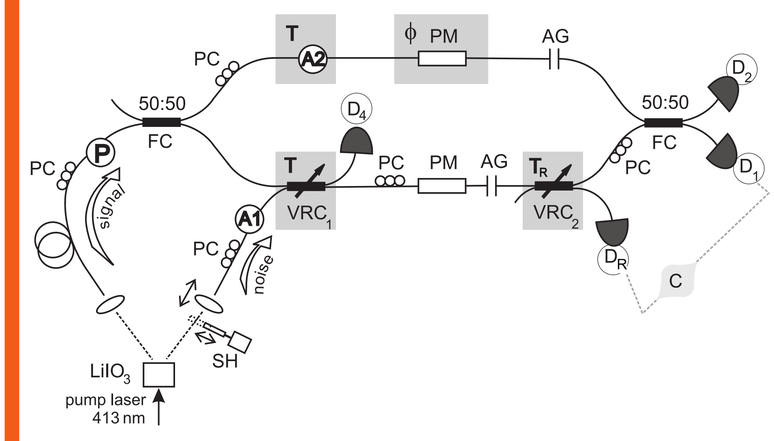
$$\text{if } \eta_A = \eta_B T$$

$$V = \frac{4\sqrt{1-T_R}}{5-4T_R}$$

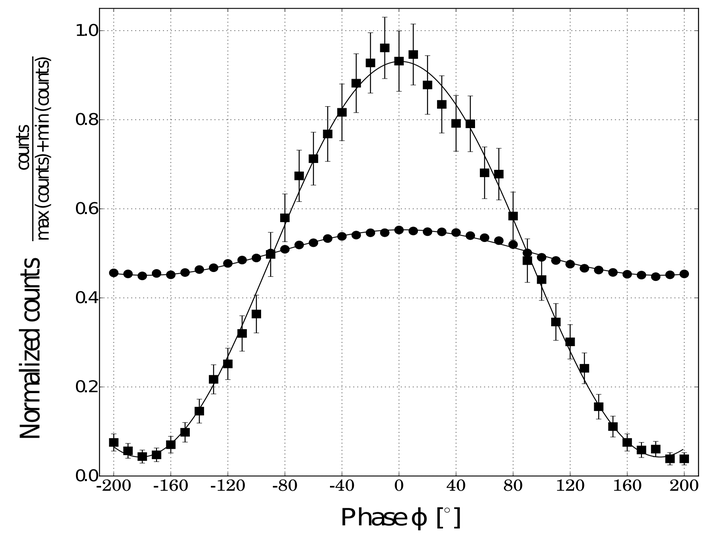
$$\text{If } T_R = \frac{3}{4}$$

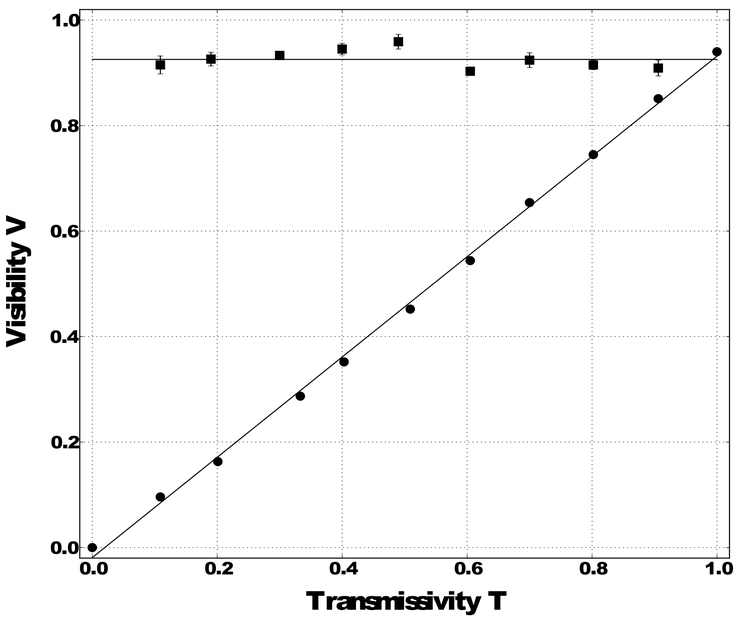
$$V = 1$$

Experiment

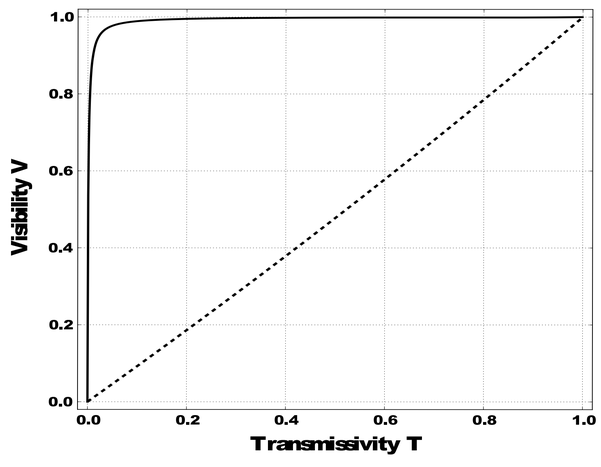


- Photons in fibre-optics two-photon Mach-Zehnder interferometer
- Signal and noise photon generated in SPDC process type I, pumping at 413 nm, LiIO3 crystal
- Noise photon coherently added to the signal photon





Behaviour of noise eater when noise extended by two-photon contributions:
$p_0|0\rangle + p_1|1\rangle + p_2|2\rangle, \qquad p_k = \lambda^k e^{-\lambda}/k!$



Project GA 205/12/0577 of GAČR

Projects PrF-2012-019 and PrF-2013-008 of PU

INVESTMENTS IN EDUCATION DEVELOPMENT