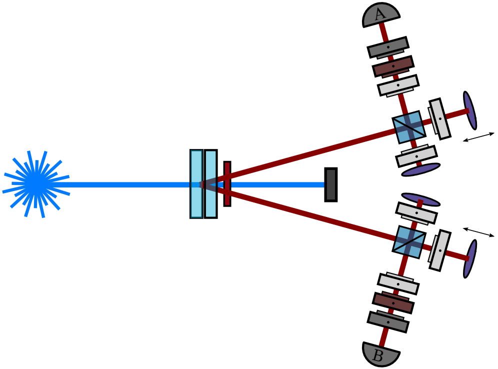
Efficacy of weak measurement reversal for stochastic amplitude damping



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March 21, 2013

Introduction
Weak Measurement Reversal
Stochastic Disturbance
Results and Future Work

Introduction

How does weak measurement reversal contend with statistically fluctuating disturbances?

Today's Talk

- Motivation/Introduction
- Weak Measurement Reversal
- *Stochastic* disturbance
- Results and future work

Introduction

Entanglement is an important resource. How can we maintain it?

Entanglement distillation:

Experimental entanglement distillation and 'hidden' non-locality

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Entangled states are central to quantum information processing, including quantum teleportation[1], efficient quantum computation[2] and quantum cryptography[3]. In general, these applications work best with pure, maximally entangled quantum states. However, owing to dissipation and decoherence, practically available states are likely to be non-maximally entangled, partially mixed (that is, not pure), or both. To counter this problem, various schemes of entanglement distillation, state purification and concentration have been proposed[4–11]. Here we demonstrate experimentally the distillation of maximally entangled states from non-maximally entangled inputs. Using partial polarizers, we perform a filtering process to maximize the entanglement of pure polarization-entangled photon pairs generated by spontaneous parametric down-conversion[12,13]. We have also applied our methods to initial states that are partially mixed. After filtering, the distilled states demonstrate certain non-local correlations, as evidenced by their violation of a form of Bell's inequality[14,15]. Because the initial states do not have this property, they can be said to possess 'hidden' non-locality[6,16].

Introduction

Entanglement is an important resource. How can we maintain it?

Decoherence free subspaces/subsystems:

Experimental Verification of Decoherence-Free Subspaces

Paul G. Kwiat,[1*] Andrew J. Berglund,[1†] Joseph B. Altepeter,[1] Andrew G. White[1,2]

Using spontaneous parametric down-conversion, we produce polarization-entangled states of two photons and characterize them using two-photon tomography to measure the density matrix. A controllable decoherence is imposed on the states by passing the photons through thick, adjustable birefringent elements. When the system is subject to collective decoherence, one particular entangled state is seen to be decoherence-free, as predicted by theory. Such decoherence-free systems may have an important role for the future of quantum computation and information processing.

PACS numbers: 89.70.+c, 03.65.Bz, 42.50.Dv

Experimental Realization of Noiseless Subsystems for Quantum Information Processing

Lorenza Viola,[1*†] Evan M. Fortunato,[2*] Marco A. Pravia,[2] Emanuel Knill,[1] Raymond Laflamme,[1] David G. Cory[2]

We demonstrate the protection of one bit of quantum information against all collective noise in three nuclear spins. Because no subspace of states offers this protection, the quantum bit was encoded in a proper noiseless subsystem. We therefore realize a general and efficient method for protecting quantum information. Robustness was verified for a full set of noise operators that do not distinguish the spins. Verification relied on the most complete exploration of engineered decoherence to date. The achieved fidelities show improved information storage for a large, noncommutative set of errors.

Weak Measurement Reversal

A third solution is to undo, or reverse a quantum measurement.

Selected for a Viewpoint in *Physics*
PRL **101,** 200401 (2008) PHYSICAL REVIEW LETTERS week ending 14 NOVEMBER 2008

Reversal of the Weak Measurement of a Quantum State in a Superconducting Phase Qubit

Nadav Katz,[1,*] Matthew Neeley,[1] M. Ansmann,[1] Radoslaw C. Bialczak,[1] M. Hofheinz,[1] Erik Lucero,[1] A. O'Connell,[1] H. Wang,[1] A. N. Cleland,[1] John M. Martinis,[1] and Alexander N. Korotkov[2]

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(Received 11 June 2008; published 10 November 2008)

We demonstrate in a superconducting qubit the conditional recovery (uncollapsing) of a quantum state after a partial-collapse measurement. A weak measurement extracts information and results in a nonunitary transformation of the qubit state. However, by adding a rotation and a second partial measurement with the same strength, we erase the extracted information, canceling the effect of both measurements. The fidelity of the state recovery is measured using quantum process tomography and found to be above 70% for partial-collapse strength less than 0.6.

DOI: 10.1103/PhysRevLett.101.200401 PACS numbers: 03.65.Ta, 03.67.Lx, 85.25.Cp

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PHYSICAL REVIEW A **82**, 052323 (2010)

Reversing entanglement change by a weak measurement

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Entanglement of a system changes due to interactions with the environment. A typical type of interaction is amplitude damping. If we add a detector to monitor the environment and only select the no-damping outcome, this amplitude damping is modified into a weak measurement. Here we show that the entanglement change of a two-qubit state due to amplitude damping or weak measurement can be probabilistically reversed. For the amplitude-damping case, the entanglement partially recovers under most conditions. For the weak-measurement case, the recovery of the initial entangled state is exact. The reversal procedure involves another weak measurement, preceded and followed by bit flips applied to both qubits. We propose a linear optics scheme for the experimental demonstration of these procedures.

DOI: 10.1103/PhysRevA.82.052323 PACS number(s): 03.67.Bg, 03.65.Yz, 42.50.Ex, 03.65.Ta

Weak Measurement Reversal

Let's see how this works

- We start with a quantum state ρ
- We perturb the state with a measurement $\hat{M}$

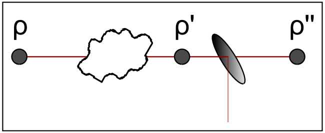
$$\rho' = \frac{\hat{M}\rho\hat{M}^\dagger}{\mathrm{Tr}[\hat{M}\rho\hat{M}^\dagger]}$$

- The fidelity may drop:

$$\mathcal{F}(\rho, \rho') = \mathrm{Tr}\left[\sqrt{\sqrt{\rho}\rho'\sqrt{\rho}}\right] \leq 1$$

- As a result, the *entanglement* may drop.
- What if we perform a second measurement, analogous to the first?

Weak Measurement Reversal



- We measure the state ρ' with a new measurement $\hat{M}'$

$$\rho'' = \frac{\hat{M}'\rho'\hat{M}'^{\dagger}}{\mathrm{Tr}[\hat{M}'\rho'\hat{M}'^{\dagger}]}$$

- For a tuned measurement, $\mathcal{F}(\rho, \rho'') = 1$

Weak Measurement Reversal

- Even after a perturbation we maintain the entanglement!
- Let's look at a specific photonic example: the singlet state with amplitude damping

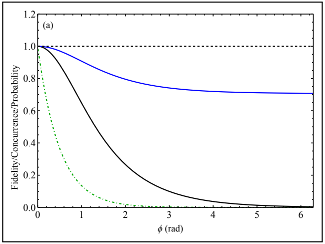
$$
\begin{aligned}
|\Psi^-\rangle &= \frac{|HV\rangle - |VH\rangle}{\sqrt{2}} \\
\hat{M} &= \hat{D} \otimes \hat{\mathbb{1}} \\
\hat{D} &= e^{-\phi}\hat{\Pi}_H + \hat{\Pi}_V,
\end{aligned}
$$

- The optimal correction $\hat{M}'$ in this case is

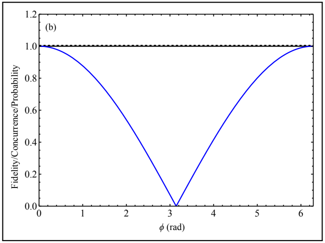
$$\hat{M}' = \hat{\mathbb{1}} \otimes \hat{D}$$

Weak Measurement Reversal

Amplitude Damping:



Phase Damping:



Blue ($\mathcal{F}$), Black (C) and Dashed Black (Corrected $\mathcal{F}$ and C)

Stochastic Disturbance, Static Correction

Let's now consider a random disturbance characterized by a Gaussian random variable $\widetilde{\phi}$.

- Mean: $\langle\widetilde{\phi}\rangle = \phi_a$
- Variance: $\sigma^2 = \langle\widetilde{\phi}^2\rangle - \langle\widetilde{\phi}\rangle^2$
- If we choose a correction to fit the mean value ϕ_a, what do we find?

Stochastic Disturbance, Static Correction

Phase Damping

$$p_p(F;\rho') = \sqrt{\frac{2}{\pi\sigma^2(1-F^2)}}\, e^{-[\phi_a - 2\mathrm{arcosh}(F)]^2/2\sigma^2}$$

$$p_p(F;\rho'') = \sqrt{\frac{8}{\pi\sigma^2(1-F^2)}}\, e^{-2\mathrm{arcosh}^2(F)/\sigma^2}$$

Amplitude Damping

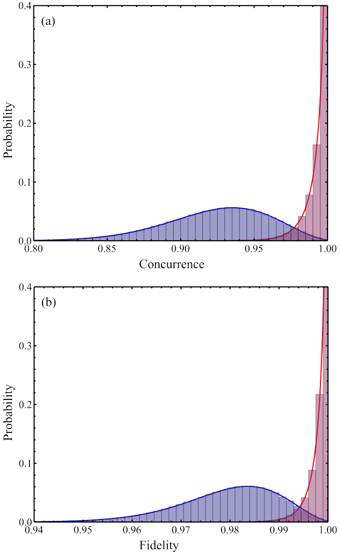
$$p_a(C;\rho') = \frac{e^{-(\phi_a+\mathrm{arsech}(C))^2/2\sigma^2}}{\sqrt{2\pi}\sigma(1-C)C}\left(1+e^{2\phi_a \mathrm{arsech}(C)/\sigma^2}\right)\sqrt{\frac{1-C}{1+C}}$$

$$p_a(C;\rho'') = \frac{e^{-\mathrm{arsech}^2(C)/2\sigma^2}}{\sigma(1-C)C}\sqrt{\frac{2(1-C)}{\pi(1+C)}}$$

$$p_a(F;\rho') = |2F^2-1|^{-1}\sqrt{\frac{2}{\pi\sigma^2(1-F^2)}}\, e^{-[\phi_a - \mathrm{arcosh}(2F^2-1)]^2/2\sigma^2}$$

$$p_a(F;\rho'') = |2F^2-1|^{-1}\sqrt{\frac{8}{\pi\sigma^2(1-F^2)}}\, e^{-\mathrm{arcosh}^2(2F^2-1)/2\sigma^2}$$

Stochastic Disturbance, Static Correction



- $\langle C \rangle = 0.92 \to 0.995$
- $\sigma_C = 0.036 \to 0.0075$
- $\langle \mathcal{F} \rangle = 0.980 \to 0.999$
- $\sigma_{\mathcal{F}} = 0.0092 \to 0.0019$

$\phi_a = \pi/8$ and $\sigma = \pi/30$

$N = 10^5$

Stochastic Disturbance, Static Correction

We can do the same analysis with three parties

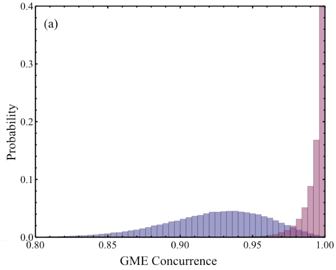
- The GHZ state with amplitude damping

$$
\begin{aligned}
|GHZ\rangle &= \frac{|HHH\rangle - |VVV\rangle}{\sqrt{2}} \\
\hat{M} &= \hat{D} \otimes \hat{\mathbb{1}} \otimes \hat{\mathbb{1}} \\
\hat{D} &= e^{-\phi}\hat{\Pi}_H + \hat{\Pi}_V,
\end{aligned}
$$

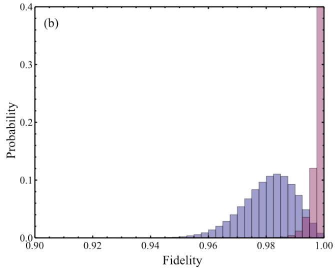
- The optimal correction $\hat{M}'$ in this case is attenuating the V polarization of any party, e.g.:

$$
\begin{aligned}
\hat{M}' &= \hat{\mathbb{1}} \otimes \hat{\mathbb{1}} \otimes \hat{D}' \\
\hat{D}' &= \hat{\Pi}_H + e^{-\phi}\hat{\Pi}_V,
\end{aligned}
$$

Stochastic Disturbance, Static Correction



- $\langle C \rangle = 0.924 \rightarrow 0.995$
- $\sigma_C = 0.036 \rightarrow 0.0075$



- $\langle \mathcal{F} \rangle = 0.981 \rightarrow 0.999$
- $\sigma_{\mathcal{F}} = 0.0091 \rightarrow 0.0019$

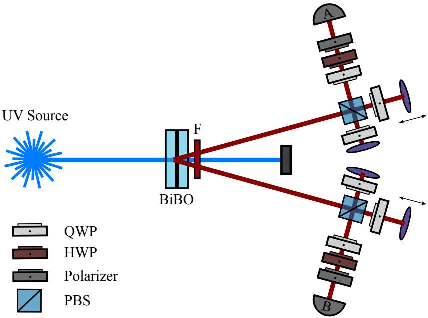
$\phi_a = \pi/8$ and $\sigma = \pi/30$

$N = 10^5$

Results and Future Work

We have shown that a random disturbance in the form of amplitude and phase damping can be corrected with high fidelity using a static (weak) measurement.

Future work:



Results and Future Work

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