Quantum State Comparison Amplifier with Feedforward State Correction

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Abstract: Here we present a probabilistic amplifier that combines two quantum state comparison amplifiers together with a feed-forward state correction strategy. Our system outperform the Unambiguous State Discrimination (USD) based amplifier in terms of the success probability-fidelity product and requires a no more complex experimental setting.

The laws of quantum mechanics pose stringent constraints on the way a quantum signal can be amplified. Deterministic amplification of an unknown quantum state always imply the addition of noise of a minimal amount of noise, linear and noiseless amplification is in principle allowed provided it works only probabilistically [1] and [2].

The state comparison amplifier [3] is an approximate probabilistic amplifier that works for a set of coherent states with unknown phase but known mean photon number. Alice picks uniformly at random an input state from the set $\{|+\alpha\rangle, |-\alpha\rangle\}$ and pass it to Bob who has to amplify it.

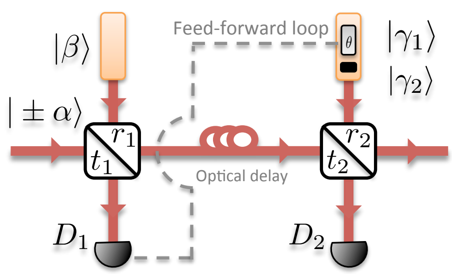

FIG. 1. Device schematics. Bob mixes Alice's input, $|\pm\alpha\rangle$ with a guess coherent state $|\beta\rangle$ at the first beam splitter. The input of the second stage is chosen according to the outcome of the first detector.

Our device is shown in figure 1. Bob mixes Alice's input with two suitable guess coherent states at the beam splitters in attempt to achieve destructive interference in both the arms that go to the APD detectors. The lack of trigger is an imperfect indication that Bob's guess is right and that the output contain the correct amplified state (the indication is imperfect because there could be undetected light due to a wrong guess). In this case the output state is passed to the second stage for further amplification. On the other hand, if D_1 fires Bob know that his guess was wrong but he can still correct the output by changing the input state for the second stage via the feed-forward loop.

The overall gain of the system is given by $g = \frac{1}{r_1 r_2}$. Since the key working point for this AMPlifier is this feed-forward State Correction we call this system SCAMP.

Bob declares success and postselects the output corresponding to the events $S = \{\{D_1 = 0, D_2 = 0\}, D_1 = 1\}$ (or simply $S = \{\{0,0\},1\}$).

The fidelity of the SCSCAMP is the probability of passing a measurement test on the output comparing it to $|g\alpha\rangle$ and the *success probability-fidelity product* [2] is the joint probability of success and of passing the measurement test:

$$\begin{aligned} P(T,S) &= P(T,\{0,0\}) + P(T,1) \\ &= \sum_{\sigma=\pm\beta} \left(P(T|\{0,0\},\sigma)P(\{0,0\}|\sigma) + P(T|1,\sigma)P(1|\sigma)\right) P(\sigma) \\ &= \frac{1}{2}\left(2 - \mathrm{e}^{-4\eta\left(1-\frac{1}{g}\right)\alpha^2} + \mathrm{e}^{-4\eta\left(1-\frac{1}{g^2}\right)\alpha^2}\mathrm{e}^{-4\left(1-\frac{1}{g}\right)^2\alpha^2}\right) \end{aligned}$$

Our figures of merit compare favorably with other schemes. In figure 2 we show that the success probability-fidelity product of the SCAMP is always bigger than the one of an USD based amplifier (see for example [2]) that, when inconclusive, delivers an uniformly at random output ($|\pm g\alpha\rangle$). Furthermore, SCAMP is almost always bigger than the $1 \to 2$ deterministic no-cloning limit of 2/3 for an arbitrary coherent state.

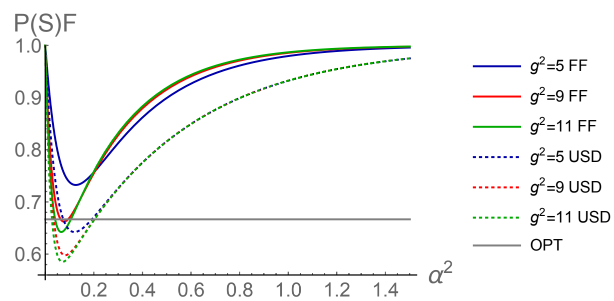

FIG. 2. Success probability-fidelity product for the SCAMP for the USD based amplifier, as explained in the main text, with gains of 5 (blue), 8 (red) and 11(green) and for the no-cloning limit (gray). The detector efficiency are assumed to be equal to 1 for simplicity but the system is resilient to inefficient detectors.

The SCAMP can be realized with classical resources (i.e., lasers, linear optics and APD detectors), the ability to switch between input states on the fly requires delay lines and fast switching but it can still be achieved with classical resources and the loss introduced by the delay can be offset at the second stage. Similar systems, with no state correction, proved to achieve high-gain, high fidelity and high repetition rates [4], [5] and [6].

Due to its simplicity, the system we propose might represent an ideal candidate either as a recovery station to counteract quantum signal degradation due to propagation in a lossy fibre or across the turbulent atmosphere or as a quantum receiver to improve the key-rate of quantum communication protocols using weak coherent states. The system is also suitable for on-chip implementation.

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