

A Learning Scheme with Coherent State Amplification

Luca Mazzarella¹, Ross Donaldson², Robert Collins², Ugo Zanforlin², David Canning², Gioan Tatti¹, Gerald Buller² & John Jeffers¹.

¹Department of Physics, John Anderson Building, University of Strathclyde, 107 Rottenrow, Glasgow G4 0NG, U.K.

²Institute of Photonics and Quantum Sciences, School of Engineering and Physical Sciences, David Brewster Building, Heriot-Watt University, Edinburgh EH14 4AS, U.K.

We show how a learning strategy combined with feed-forward can improve the performance of a probabilistic optical amplification scheme.

Quantum mechanics poses stringent constraints on the way a quantum signal can be amplified. Deterministic amplification of an unknown quantum state always implies the addition of a minimal amount of noise. Linear and noiseless amplification is allowed in principle provided that it only works probabilistically [1] and [2].

The State Comparison AMPLifier (SCAMP) [3] is an approximate probabilistic amplifier that works for a set of coherent states with unknown phase but known mean photon number.

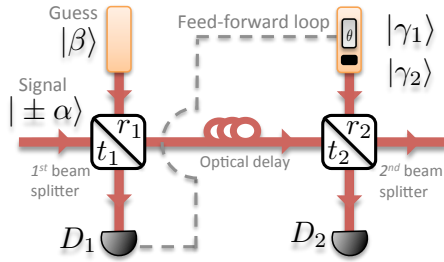


Figure 1: Bob mixes Alice’s input, $|\pm\alpha\rangle$ with a guess coherent state $|\beta\rangle = |t_1\alpha/r_1\rangle$ at the first beam splitter. The input of the second stage is chosen according to the outcome of the first detector. When there is no event at D_1 Bob will use $|\gamma_1\rangle = |t_2/r_1r_2\rangle\alpha$ otherwise he can correct the output using $|\gamma_2\rangle = |-\frac{1}{t_2}\left(\frac{t_2^2+2t_1^2r_2^2}{r_1r_2}\right)\alpha\rangle$.

Our device is shown in figure 1. Alice selects randomly an input state from the set $\{|\alpha\rangle, |-\alpha\rangle\}$ and passes it to Bob to amplify. He does so by mixing it with guess coherent states at the beam splitters in an attempt to achieve destructive interference in both of the arms that reach the single-photon avalanche diode (SPAD). If a detector does not fire this is an imperfect indication that Bob’s guess is right and that the output arm contains the correct amplified state (the indication is imperfect because the detector will not always fire if a coherent state is incident on it). When there is no event at D_1 the output state is passed to the second stage for further amplification. On the other hand, if D_1 fires, Bob knows that his guess was wrong, but can still correct the output by changing the input state at the second stage via the feed-forward loop. This system has been named a State Correction State Comparison Amplifier or SCSCAMP.

In summary, Bob declares success when both the detectors do not fire or when the first detector does fire and state correction is performed. The overall gain of the system is given by $g^2 = 1/(r_1^2r_2^2)$, where r_i^2 is the reflexivity of the i -th beam splitter. We generalize our strategy for an arbitrary number of input states and beam splitters. At each stage the optimal guess can be computed via the maximum likelihood

taking into account the previous guesses [4].

The success probability-fidelity product ($P(S)F$) [2] of the SCSCAMP is the joint probability of success and of passing a measurement test on the output comparing it to correctly amplified state.

The device’s figures of merit compare favorably with other schemes. In figure 2, we show that the success probability-fidelity product of the SCSCAMP is larger than that of a Unambiguous State Discrimination (USD) based amplifier (see for example [2]) that, when inconclusive, delivers a best guess random output (for a two word alphabet, a random choice between $|\pm g\alpha\rangle$). For simplicity we assume perfect detection efficiency but note that the system is resilient to inefficient detectors.

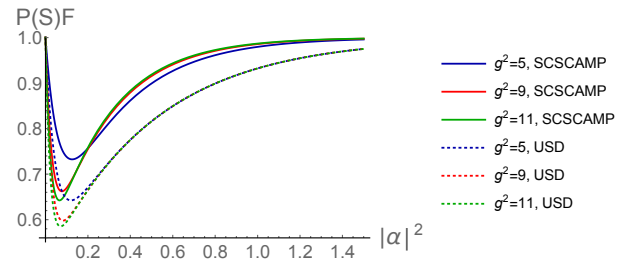


Figure 2: Success probability-fidelity product for the SCSCAMP (solid lines) for the USD based amplifier (dashed lines) against the input mean photon number per pulse, $|\alpha|^2$, with gain of 5 (blue), 8 (red) and 11 (green).

The SCSCAMP is realized with classical resources, allowing for high repetition rates and it suitable for on-chip implementation. Similar systems, with no state correction, have been proven to achieve high-gain, high fidelity and high repetition rates [5], [6] and [7].

The optimization of the guesses based on our learning scheme allow us to outperform the USD based amplifier in terms of the success probability-fidelity product. Experimental implementation of such a SCSCAMP system is no more complex than a USD system. Due to its simplicity, a SCSCAMP represents an ideal candidate as a recovery station to counteract quantum signal degradation due to propagation in a lossy medium.

The work was supported by the QComm Quantum Communication Hub of the UK Engineering and Physical Sciences Research Council (EP/M013472/1).

[1] T.C. Ralph & A.P. Lund, Proceedings of the 9th QCMC Conference 2009.

[2] S. Pandey, et al., Phys. Rev. A 88, 033852 (2013).

[3] E. Eleftheriadou et al., Phys. Rev. Lett. 111, 213601 (2013).

[4] L. Mazzarella et al., in preparation.

[5] R. Donaldson et al., Phys. Rev. Lett. 114, 120505 (2015).

[6] M.A. Usuga et al., Nat. Phys. 6, 767 (2010).

[7] R. Donaldson et al., in preparation.