Trading off Wigner negativity and decoherence time for cubic Gaussian states

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Cubic phase states are crucial resources in the development of quantum computation as they allow for universal quantum computation. However, ideal cubic phase states (CPS) are non-physical as they are nonnormalizable and have diverging photon number. The cubic squeezed state is an approximation of the ideal CPS that avoids these divergences and allows to estimate physical quantities.

In this work, we provide a thorough description of the cubic Gaussian state, a state that is obtained when a cubic gate is applied to a Gaussian state. Here, we consider the full 6-parameter familly (squeezing, rotation, thermal photons, displacement and cubicity) of Wigner quasi-probability distributions of the single-mode cubic Gaussian state and we derive asymptotic upper bounds for its Wigner negativity. We show that the Wigner negativity is determined by a single effective parameter λ.

We study the trade-off that exists between the Wigner negativity and the decoherence time of the cubic Gaussian states through the Quadrature Coherent Scale (QCS). Maximizing the decoherence time of the cubic Gaussian states for a fixed Wigner negativity, we conclude that there exists an optimal choice of squeezing and cubicity. Therefore, while one can always increase the Wigner negativity for these states by increasing the squeezing, this comes at a cost in terms of an increased decoherence time.

Furthermore, we put our results in contrast to other nonclassical states such as the Fock states. We observe that, at fixed Wigner negativity, the optimal cubic Gaussian states have a similar, but slightly lower, QCS than the Fock states up to Fock states $n = 13$. Hence, their decoherence times are comparable and close.

We also study the effect of the thermal photons in the construction of the cubic Gaussian state on its Wigner negativity and QCS. Wigner negativity is lost more rapidly than the QCS when the number of thermal photons grows. We observe that for large values of the effective parameter λ, half the negativity is lost for a thermal weight value of 1/3 and half the QCS is lost for a thermal weight value of 1/2.

Finally, we compare the cubic Gaussian states' ability to create entangled states by interacting two replicas on a balanced beam-splitter to the one of the Fock states for the same Wigner negativity. Here, optimized cubic Gaussian states show a larger entanglement that the Fock states but with a similar scaling behaviour.

In conclusion, cubic Gaussian states have been described and several properties have been analysed such as their Wigner negativity, decoherence time through QCS and entanglement. Their QCS and entanglement have been compared to Fock states displaying the same amount of Wigner negativity.

This work is based on [1].

[1] M. Arnhem, V. Crescimanna, Giuseppe Patera, and Stephan De Bièvre, Maximizing the decoherence time of cubic Gaussian states at fixed Wigner negativity, in preparation.