Hong-Ou-Mandel Effect via Hybrid Quantum Non-Demolition Gate

Alisa Manukhova*, **Andrey Rakhubovsky, Radim Filip**

Department of Optics, Palacký University, Olomouc, Czech Republic
*E-mail: alisadmitrievna.manukhova@upol.cz

We build a high-quality hybrid Quantum Non-Demolition(QND) gate between an atomic ensemble and a mechanical oscillator in the separated optical cavities connected by propagating optical pulses [1]. We demonstrate that the built gate allows to obtain the effect similar to the well-known Hong-Ou-Mandel effect [2].

The basic principle to realize the gate between an atomic ensemble and a mechanical oscillator is the following: a squeezed quantum field successively passes through the atomic ensemble, located in the cavity with optical decay rate κ_a, and the optomechanical cavity with optical decay rate κ_m accompanied by strong classical driving. Both driving fields are the pulses with rectangular time profiles, of duration τ and have a certain phase. To describe the atomic subsystem we consider the state of an ensemble of atoms at room temperature, each having two stable ground states. We assume a strong magnetic driving along the Z-axis for the atomic ensemble that allows us to apply the Holstein-Primakoff transformation and consider normalized collective spins $\left\{\hat{X}_a, \hat{P}_a\right\}$ as very longlived canonical atomic variables. To describe the optomechanical part of the system we use quadratures $\left\{\hat{X}_m, \hat{P}_m\right\}$ that refer to the dimensionless position and momentum of the mechanical oscillator. Differently to the atomic ensemble the mechanical mode is connected to a relatively hot thermal bath. The built QND gate transforms the initial quadratures $r^{in} = \left(\hat{X}_a(0), \hat{P}_a(0), \hat{X}_m(0), \hat{P}_m(0)\right)$ to the final quadratures $r^{out} = (x_a, p_a, x_m, p_m)$ as:

$$\begin{cases} x_a = \hat{X}_a(\tau) = \mathfrak{I}_a \hat{X}_a(0) + G\hat{X}_a(0) + \mathfrak{N}_{X_a}, \\ p_a = \hat{P}_a(\tau) = \mathfrak{I}_a \hat{P}_a(0) + \mathfrak{N}_{P_a}, \\ x_m = \hat{X}_m(\tau) = \mathfrak{I}_m \hat{X}_m(0) + \mathfrak{N}_{X_m}, \\ p_m = \hat{P}_m(\tau) = \mathfrak{I}_m \hat{P}_m(0) - G\hat{P}_a(0) + \mathfrak{N}_{P_m}, \end{cases} \tag{1}$$

where G is the controllable gain of the QND gate, $\mathfrak{I}_{a,m}$ are the transfer factors and $\mathfrak{N}_{X_{a,m},P_{a,m}}$ describe the excess noises that reduce the quality of the gate.

To prove the ability of the built gate to demonstrate the Hong-Ou-Mandel effect we assume $|1_a 1_m\rangle$ as the state at the input of the both, gate and beam-splitter(BS) with the transmittance coefficient T, and compare the states at the outputs. We use the language of the Wigner function and density matrix [3] and investigate corresponding matrix elements in a subspace $|1_a 1_m\rangle$, $|0_a 2_m\rangle$, $|2_a 0_m\rangle$.

Figure 1 demonstrates the dependencies of the matrix elements for the gate in the ideal adiabatic case and for the BS-case. Note that for the BS-case green curve characterizes the case to detect one photon at the each output of the BS and tends to zero when $T = 0.5$. Curves for the gate-case have very similar behavior and the green one also has the minimum for the certain value of the gain. Same results can be obtained for the non-ideal case of the QND gate.

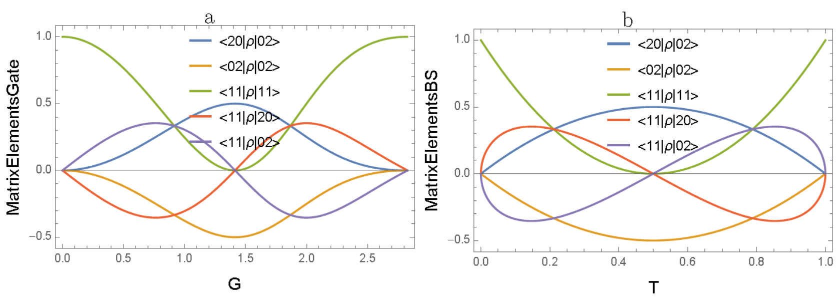

Figure 1: (a) Normalized matrix elements for the output state in the ideal adiabatic case of the gate with the gain G. (b) Matrix elements for the BS-case with the transmittance coefficient T.

References

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