Quantum States in Nonlinear Coupler with Frequency Mismatch

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1. Introduction

The effects of squeezing have been of great importance in quantum computing [1], as evidenced in the studies of squeezed light presented in the literature [2]. The present work discusses on the possibility of enhancing squeezing using nonlinear coupler utilizing different operating frequencies of the input modes. In our two-channel model, one of the channels contains the fundamental mode, whereas the other one confines the next two higher-order modes. Here we examine numerically the effect of frequency mismatch on the dynamics of the generated squeezed light.

2. Theoretical Aspects

Figure 1 shows the model considered here. The Hamiltonian for the system can be written as [3,4]

$$\hat{H} = \hbar\left\{\sum_{i=1}^{3}\left(\omega_i\hat{b}_i^\dagger\hat{b}_i + g\hat{b}_i^{\dagger 2}\hat{b}_i^2\right) + k_1\left(\hat{b}_1^\dagger\hat{b}_2 + \hat{b}_2^\dagger\hat{b}_1\right) + k_2\left(\hat{b}_1^\dagger\hat{b}_3 + \hat{b}_3^\dagger\hat{b}_1\right)\right\}$$

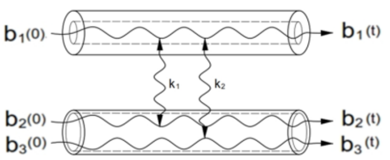

Fig. 1. Model of the three-modes co-directional Kerr nonlinear coupler.

Here the former Hamiltonian $\hat{b}^\dagger\hat{b}$ is the ladder operator, $\hbar$ is the reduced Plank constant, ω is the input frequency, g is the self-action Kerr coupling and k is the linear evanescent coupling. Using the positive P representation, we derived the exact Fokker-Planck equation without the loss of generality, which is then converted to an equivalent set of Stochastic equations, following the standard Ito calculus. Squeezing is numerically examined in term of the quadrature evolution, given by

$$(\Delta X_1)^2 = \frac{1}{4}\left[\langle\hat{b}^2\rangle + 2\langle\hat{b}^\dagger\hat{b}\rangle + \langle\hat{b}^{\dagger 2}\rangle - \langle\hat{b}\rangle^2 - \langle\hat{b}^\dagger\rangle^2 - 2\langle\hat{b}\rangle\langle\hat{b}^\dagger\rangle + 1\right]$$

$$(\Delta X_2)^2 = \frac{1}{4}\left[-\langle\hat{b}^2\rangle + 2\langle\hat{b}^\dagger\hat{b}\rangle - \langle\hat{b}^{\dagger 2}\rangle + \langle\hat{b}\rangle^2 + \langle\hat{b}^\dagger\rangle^2 - 2\langle\hat{b}\rangle\langle\hat{b}^\dagger\rangle + 1\right]$$

where fluctuations below zero indicate the presence of single-mode squeezing [4].

3. Discussion

Figure 2a exhibits the comparison between squeezing with and without frequency mismatch in the first channel using coherent initialization. The maximal squeezing is sensitive to the frequency difference $\Delta\omega_{1,2}$ between the modes in different channels, and squeezing increases due to frequency mismatch. Figure 2b depicts comparison of the first quadrature evolution for all modes ($\Delta\omega_{1,2} \neq 0$). Although only one quadrature evolution is portrayed, the squeezed quadrature between two variances are closely identical. Maximal squeezing appeared at the fundamental mode of channel two, where the excitation frequency is large. Figure 2c shows comparison between squeezing with and without frequency mismatch for coherent (first channel) and vacuum (second channel) excitations. The used combination of input parameters considering frequency mismatch provides the largest squeezing. Similar behavior is observed in the second channel; however, the amount of squeezing is minimal. As opposed to the maximal squeezing obtained with coherent initialization in all channels, maximal squeezing appeared in the first channel where the frequency excitation is the smallest, as shown in fig. 2d.

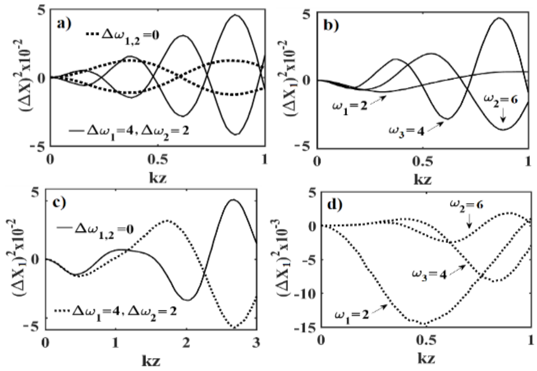

Fig. 2. Squeezing vs. dimensionless parameter kz; z being the direction of propagation. (a) Both quadrature in the first channel with and without frequency difference, (b) the first quadrature for all modes with frequency difference, (c) the first quadrature in the first channel with frequency difference, (d) the first quadrature for all modes with frequency difference. Input parameters are $\Delta\omega_1 = \omega_2 - \omega_1$, $\Delta\omega_2 = \omega_3 - \omega_1$, $k_1 = k_2 = k = 1$, $g = 0.01$.

4. Conclusion

The results reveal the system as providing an effective way to obtain enhanced squeezing. Such interaction scheme can be potentially useful to further improve squeezing in other configurations like multichannel- Kerr and second-harmonic generation [5,6].

References

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