Modelling Nonlinear optics with the Bloch-Messiah reduction

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Overview

- What is nonlinear optics?
- Why do we care about it?
- What I have been doing
- Gaussian optics
- Outlook

Motivation

The good

Spontaneous Parametric processes, SPDC, SFWM

- Heralded single photon sources
- Entangled photon pair generation (polarisation, spatial)

Kerr processes

- Self-Phase modulation (SPM) for generating Bannana states (CV)
- Cross-Phase modulation (XPM) for sensing

The bad

- Generating more than two photons -> bad for quantum computing

All Kerr nonlinear processes

- SPM -> Spectral broadening
- XPM -> Unwanted phase shifts on single photons due to propagation of the pump

What do we mean by nonlinear optics?

- Roughly processes that conserve energy but do not conserve photon number.

$$\vec{P} = \chi^{(1)}\vec{E}_1 + \chi^{(2)}\vec{E}_1\vec{E}_2 + \chi^{(3)}\vec{E}_1\vec{E}_2\vec{E}_3 + \dots \tag{1}$$

Here we are going to talk about squeezing, i.e SPDC or SFWM, Hamiltonians are then of the form,

$$\hat{H} = A\hat{a}_S^\dagger\hat{a}_I^\dagger\hat{a}_P + h.c. \tag{2}$$

$$\hat{H} = A\hat{a}_S^\dagger\hat{a}_I^\dagger\hat{a}_P\hat{a}_P + h.c. \tag{3}$$

Note for the rest of this presentation I will drop the hat notatiaion and using the convention a, b are annihilation operators in modes a & b

Hamiltonian

$$\hat{U} = \exp\left[-\frac{i}{\hbar}\left(A\int d\omega_1 \int d\omega_2 f(\omega_1,\omega_2)\hat{a}_1^\dagger(\omega_1)\hat{a}_2^\dagger(\omega_2) + h.c.\right)\right] \tag{4}$$

We can do re-write this Hamiltonian as a Schmidt-decomposition using a SVD.

$$-\frac{i}{\hbar}Af(\omega_1,\omega_2) = \sum_k r_k \psi_k(\omega_1)\phi_k(\omega_2) \tag{5}$$

Gaussian Optics

- Using the undelpeted pump approximation we can write the Hamiltonians as terms which are at most quadratic in creation and annihilation operators.
- These are Gaussian transforms, they take Gaussian states to Gaussian states

$$\begin{bmatrix} \vec{b} \\ \vec{b}^{\dagger} \end{bmatrix} = M \begin{bmatrix} \vec{a} \\ \vec{a}^{\dagger} \end{bmatrix} \tag{6}$$

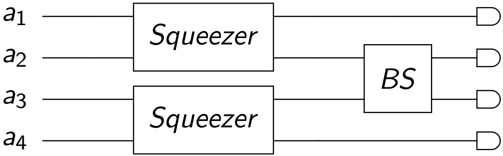

Figure: Two source HOM dip

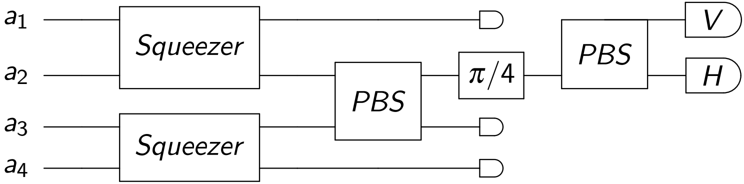

Figure: Type-1 Fusion gate

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