

Modelling Nonlinear optics with the Bloch-Messiah reduction

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Overview

Modelling
Nonlinear
optics with
the
Bloch-Messiah
reduction

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

Motivation quantum nonlinear optics

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The good

Spontaneous Parametric processes, SPDC, SFWM

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

Kerr processes

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

The bad

- Generating more than two photons \rightarrow bad for quantum computing

All Kerr nonlinear processes

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

What do we mean by nonlinear optics?

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

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

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

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

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

Gaussian Optics

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$$\hat{U} = \exp \left[-\frac{i}{\hbar} \left(\overset{\text{Power}}{P} \int d\omega_1 \int d\omega_2 \overset{\text{JSA}}{f(\omega_1, \omega_2)} \overset{\text{Signal \& Idler}}{\hat{a}_s^\dagger(\omega_1) \hat{a}_i^\dagger(\omega_2)} + h.c. \right) \right] \quad (4)$$

- Using the undepleted 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 ¹

$$\begin{bmatrix} \vec{b} \\ \vec{b}^\dagger \end{bmatrix} = M \begin{bmatrix} \vec{a} \\ \vec{a}^\dagger \end{bmatrix} \quad (5)$$

¹These are linear symplectic transforms which conveniently can be written as a matrix

Hamiltonian

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

$$-\frac{i}{\hbar}Pf(\omega_1, \omega_2) = \sum_k r_k \psi_k(\omega_1) \phi_k(\omega_2) \quad (6)$$

Where ψ & ϕ are unitary matrices,

- with $\psi_k(\omega_1)$ is the k -th row and ω_1 -th column of $u_{(\omega_1, k)}$,
- with $\phi_k(\omega_2)$ is the ω_2 -th row and k -th column of $v_{(k, \omega_2)}^\dagger$

$$P'f(\omega_1, \omega_2) = \sum_k r_k u_{(\omega_1, k)} v_{(k, \omega_2)}^\dagger \quad (7)$$

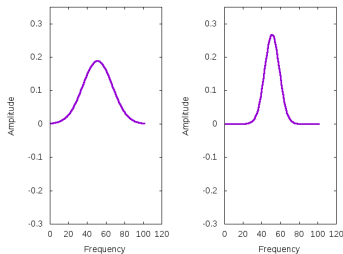
Recall SVD is defined as,

$$M = U \Sigma V^\dagger \quad (8)$$

The Joint Spectral Amplitude (JSA)

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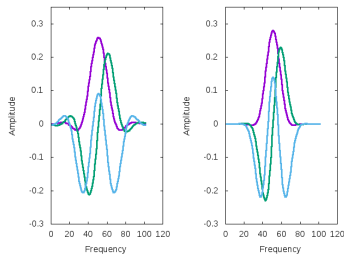


(a) Signal (red) and Idler
(blue)

Non-separable JSAs

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(a) Signal (red) and Idler
(blue)

Types of Gaussian transformations

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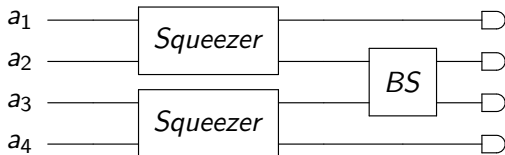


Figure: Two source HOM dip

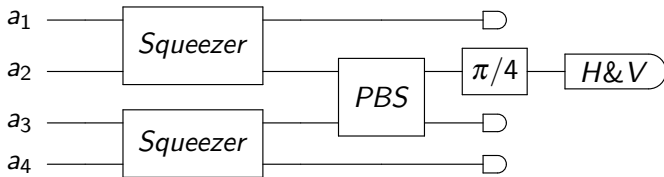
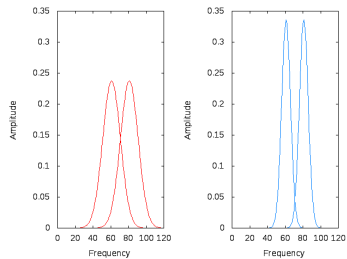


Figure: Type-1 Fusion gate

Two squeezers JSA

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G(4) correlation function

$$G^{(4)} = \frac{\langle \hat{a}_1^\dagger \hat{a}_2^\dagger \hat{a}_3^\dagger \hat{a}_4^\dagger \hat{a}_1 \hat{a}_2 \hat{a}_3 \hat{a}_4 \rangle}{\langle \hat{a}_1^\dagger \hat{a}_1 \rangle \langle \hat{a}_2^\dagger \hat{a}_2 \rangle \langle \hat{a}_3^\dagger \hat{a}_3 \rangle \langle \hat{a}_4^\dagger \hat{a}_4 \rangle} \quad (9)$$

Outlook

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- There is much to do