

# Modelling Nonlinear optics with the Bloch-Messiah reduction

Oliver Thomas

Quantum Engineering CDT  
University of Bristol

August 20, 2018

# Animation

Modelling  
Nonlinear  
optics with  
the  
Bloch-Messiah  
reduction

Oliver Thomas

# Overview

Modelling  
Nonlinear  
optics with  
the  
Bloch-Messiah  
reduction

Oliver Thomas

- 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  $\rightarrow$  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?

- 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,

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

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

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

# Hamiltonian

Modelling  
Nonlinear  
optics with  
the  
Bloch-Messiah  
reduction

Oliver Thomas

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

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

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

Where  $\psi$  &  $\phi$  are unitary matrices,

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

$$P'f(\omega_1, \omega_2) = \sum_k r_k u_{(\omega_1, k)} v_{(k, \omega_2)}^\dagger \quad (6)$$

Recall SVD is defined as,

$$M = U \Sigma V^\dagger \quad (7)$$



# Gaussian Optics

Modelling  
Nonlinear  
optics with  
the  
Bloch-Messiah  
reduction

Oliver Thomas

- Using the undelapeted 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

$$\begin{bmatrix} \vec{b} \\ \vec{b}^\dagger \end{bmatrix} = M \begin{bmatrix} \vec{a} \\ \vec{a}^\dagger \end{bmatrix} \quad (8)$$

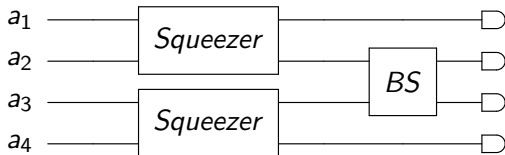


Figure: Two source HOM dip

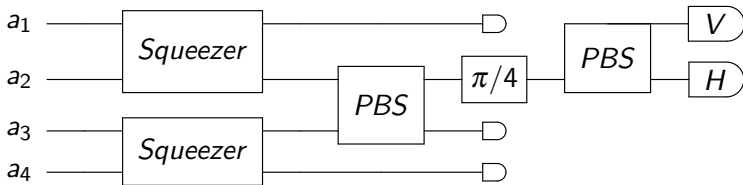


Figure: Type-1 Fusion gate

# Overview

Modelling  
Nonlinear  
optics with  
the  
Bloch-Messiah  
reduction

Oliver Thomas

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

# Overview

Modelling  
Nonlinear  
optics with  
the  
Bloch-Messiah  
reduction

Oliver Thomas

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