Problem : Current techniques to generate single photons are expensive, hard to come by and difficult to tune to the parameters required for quantum technologies

Current techniques : Spontaneous break-up of single high-energy photon from a bright light source (pump) into two low energy photons (signal & idler), such that total conserved energy $\hbar w_p = \hbar w_s + \hbar w_i$

Process triggered by an interact° with matter in which photons propagate

Matter: Non-linear crystals that lack invers° symmetry ~ k2 materials
→ Lithium Niobate ($LiNbO_3$)

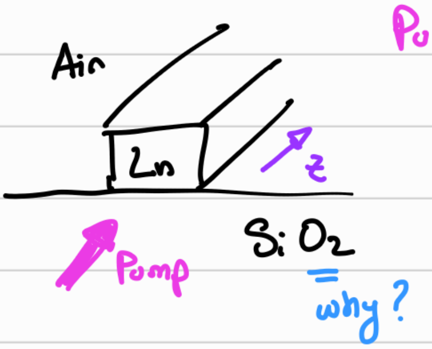
Parameters: Obtaining $\lambda \simeq 750$ nm

Goal: Investigate alternative "cheaper" scheme

↓

combinat° of second harmonic generat° & photon pair generat° into a "dual rail" photonic nanowire setup

① Photon pair generat°



Pump : classical source of light
$2 \times$ freq <=> $2 \div$ wavelength

Goal 1500 nm pump => 750 nm photon

Setup => Spontaneous effect

ω_p ↑ ↓ ω_s

a pump of photons : pair $\downarrow \omega_i$

where $\Sigma \lambda$ = original photon λ

specific combinat° can be achieve : structure

System : can be described by a f°: $A_p(z,t)$

↳ effectively this is a numerical evaluat° of integrals

↳ part of the modelling consists on testing / figuring out the properties of ω_s, ω_i

Modelling the Pump Field - Samuel Winter diss

Firstly, the propagation constants β_m and their jth derivatives, with respect to angular frequency ω, β_{mj}, were found for the chosen geometry parameters using COMSOL. Here, $m \in \{f, s, p\}$ denotes the chosen mode for the fundamental mode that is excited using the telecommunications laser in waveguide 1, the mode chosen for the second harmonic in waveguide 1, and the mode that will pump the SPDC process in waveguide 2. The free space wavelengths of photons in each mode are $\lambda_f = 1.504$ μm and $\lambda_s = \lambda_p = 0.752$ μm. The propagation of each mode down the length of the waveguide is modelled using a normalised field envelope function U_m. To solve the equations numerically, the field amplitudes and coordinates are normalised and set into the reference frame of the fundamental mode pulse. The normalised distance coordinate $\xi = y/y_d$, where $y_d = 2t_0^2/|\beta_{f2}|$ is the dispersion length. The normalised time coordinate $\tau = (t - y\beta_f)/t_0$ is set such that the centre of the pulse in the fundamental mode always has $\tau = 0$. The fields are scaled as $U_f = \sqrt{2}\rho_2 y_d A_f$ and $U_{s,p} = \rho_2 y_d A_{s,p}$ such that $|A_m|^2$ yields the intensity in watts. ρ_2 is the effective non-linear coefficient. The evolution of all 3 fields is described by [19–21]

(*)
$$\begin{cases} i\partial_\xi U_f = -\cancel{r_2\partial_\tau^2 U_f} - U_s U_f^* e^{i\kappa\xi} \\ i\partial_\xi U_s = -\cancel{s_1\partial_\tau U_s} - \cancel{s_2\partial_\tau^2 U_s} - \dfrac{U_f^2}{2} e^{-i\kappa\xi} + gU_p \\ i\partial_\xi U_p = -\cancel{p_1\partial_\tau U_p} - \cancel{p_2\partial_\tau^2 U_p} + gU_s \end{cases} \tag{3}$$

Start : ignore t dependency

$$\begin{cases} i\partial_\xi U_f = -U_s U_f^* e^{ik\xi} & (1) \\ i\partial_\xi U_s = -\dfrac{U_f^2}{2} e^{-ik\xi} + gU_p & (2) \\ i\partial_\xi U_p = gU_s & (3) \end{cases}$$

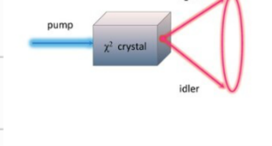
MODES

f : fundamental mode that is excited in waveguide 1

s : mode chosen for second harmonic in waveguide 1

p : mode that will pump the SPDC process in waveguide 2

Spontaneous Parametric Down Convers° :



U_{mode} : normalised field envelope f°

↳ models the propagat° of each mode down the length of the waveguide

FIELD AMPLITUDES & COORDS

ξ : Normalised distance coordinate $\xi = y / y_d$

dispers° length: $y_d = 2t_0^2 / |\beta_{f2}|$

τ : time coordinate $\tau = (t - y\beta_f)/t_0$

↑ set such that in fundamental mode, center of the pulse $\tau = 0$

→ Fields are scalled as : $U_f = \sqrt{2}\, \rho_2 y_d A_f$

$U_{s,p} = \rho_2 y_d A_{s,p}$

s.t $|A_m|^2$ yields the intensity in [watts]

ρ_2 = effective non-linear coeff

$r_2 = -\beta_{f2} / |\beta_{f2}|$

$s_2 = -\beta_{s2} / |\beta_{f2}|$ $\quad s_1 = y_d / y_{ws}$

$p_2 = -\beta_{p2} / |\beta_{f2}|$ $\quad p_1 = y_d / y_{wp}$

$y_{wm} = t_0 / (\beta_m - \beta_f)$: walk-off length

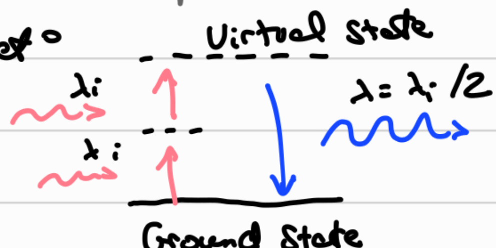
note : $y_{wf} = 0$

κ : phasematching parameter $\kappa = -y_d \Delta\beta$

$= -y_d (2\beta_f - \beta_s)$

SHG most efficient when $\Delta\beta = 0$

Second Harmonic Generat°

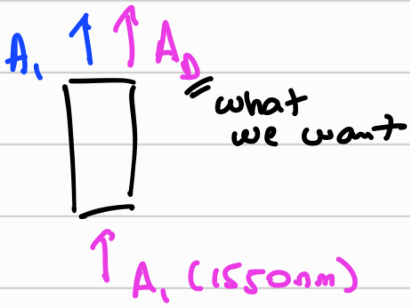


g: normalised coupling const $g = y_d C$

② Second Harmonic Generat°

Lasers source available 1500 nm $\xrightarrow{\text{GOAL}}$ convert it to 750 nm

$\longrightarrow$ frequency ×2



SHG = process deterministic

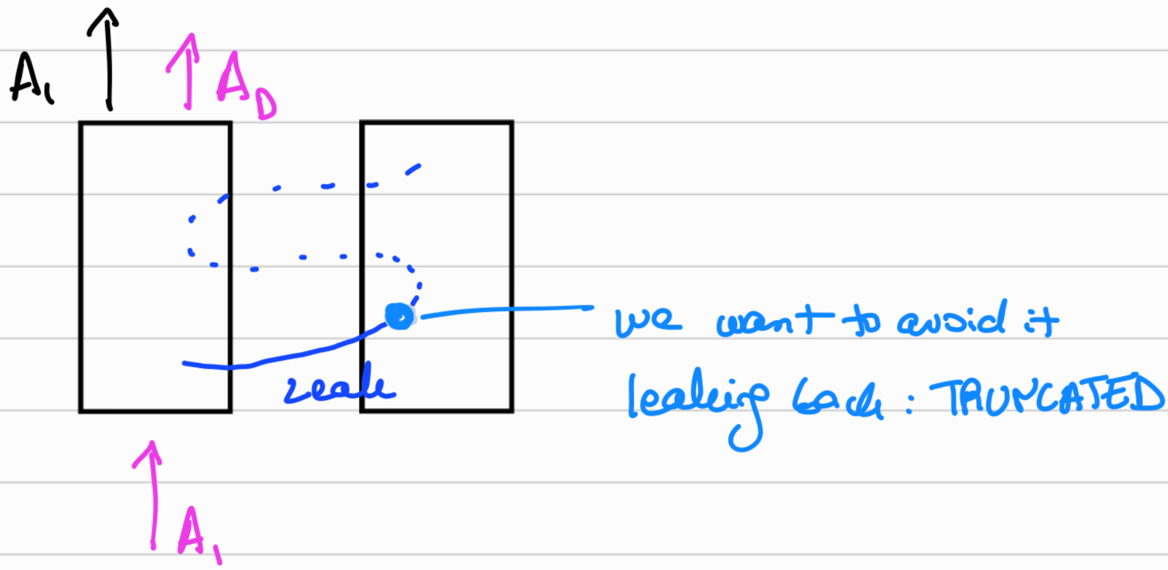
JOINT ARCHITECTURE

In a joint architecture we don't want the result of ① to overlap with the pump of ②

To avoid this, many groups use a filter

our project proposes an alternative to this

~ coupled pendulum



LEAK:

Transverse distribut° of the electric field of the first waveguide overlaps with the second waveguide.

evenecent tails

periodic power transfer

Note: Coupling needs to occur at the wavelength that we want

↳ we are engineering the {size, shape} waveguides

Longitudinal component of the wavevector

↓

How fast the phase of light evolves

↓

Efficient light / power transfer

We can control the wavector by the geometry of wavelengths

↓

This essentially is an IVP : $\underbrace{\text{Initial Value Problem}}$

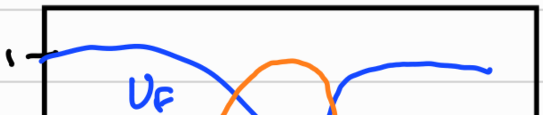
solvable via Runge-Kutta Methods (4th order)

sim techniques, 4 lines of code

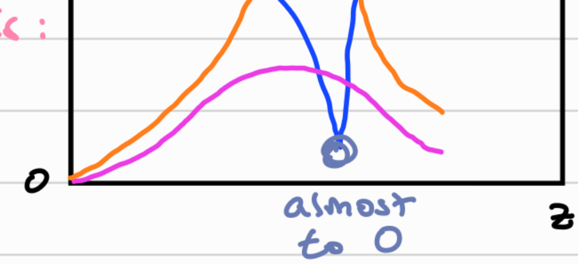
kill t dependency for now : $S_t \to 0$

- $U_p(z=0) = U_{p_0}$
- $U_{s,p}(z=0) = 0$

GOAL



We want to obtain smth like this:



Literature:
- optical waveguides EM2
- parameter down convers°
- 2nd order generat°
- quantum optics

→ Andryi has papers on engineering waveguides for parametric down convers°

TASK:
- [ ] Read departamental safety handbook: Sect°s 1-5
- [ ] Fill in health & safethy form