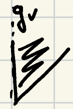
Semester 2

Modelling of photon-pair generat° in dual-rail lithium niobate photonic nano-wire set up

Meeting 6th Feb (start 2nd semester work)

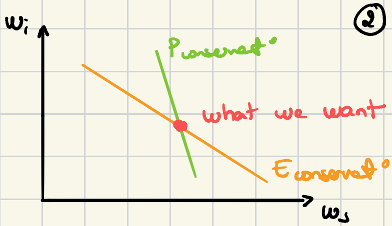
TODO
☐ Fix group velocity plots : not alligned the "right" way in P
- add lines



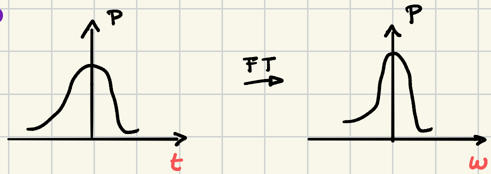
Error in presentat°: χ_2 materials are required for SPDC
nothing todo with keeping pulses in waveguide

SPDC has 2 requirements :
① Energy conservat°
$W_p = W_s + W_i$
② Momentum conservat°
$B(W_p) = B(W_s) + B(W_i)$

} similar but not the same outside of vacuum
$B = \underbrace{n_e}\, k = n_e \frac{\omega}{c}$
vacuum $n_e = 1$



TODO
☐



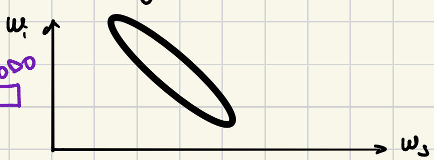
Heisenberg principle

definite momentum if no idea where positioned
- no definite momentum : "spread"

we find a middle point when both are available

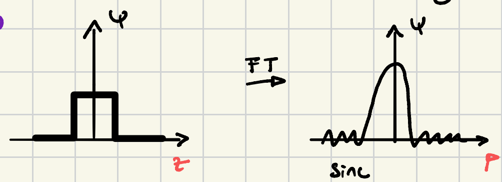
spread of freq in P

TODO
☐



Heisenberg ⇒ gives us length of waveguide Δz ∴ no uncertainty in Δp

TODO
☐



Check : Formula 4 Sam Esenine

wavef° resulting 2 photons JSA (Joint spectrum amplitude)
JSI (... intensity

$|\Psi_2\rangle = \iint f(\omega_i, \omega_s)\, |\omega_i\rangle |\omega_s\rangle \, d\omega_i \, d\omega_s$

$J = \alpha(\omega_s, \omega_i)\, \Phi(\omega_s, \omega_i)$

spectrum of pump ↑ ↑ sinc f° cone of P

$W_p = \omega_s + \omega_i$

$\Delta\beta$ = momentum mistmatch

$\Delta\beta = \beta_p - \beta_s - \beta_i$

Tuesday 13th

$$J(\omega_s,\omega_i) \;=\; \rho_2 exp\left\{\frac{(\omega_p \;-\; \omega_s \;-\; \omega_i)^2\, t_0^2}{2}\right\} sinc\left[\frac{\Delta\beta L}{2}\right] exp\left\{i\frac{\Delta\beta L}{2}\right\} \qquad (7)$$

Integral eqt° 7 $\sim sinc\left(\frac{\Delta\beta L}{2}\right)$

$\Delta\beta = \beta_p - \beta_s - \beta_i$

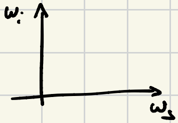
1.35 — 1.65 } wavelengths $\longrightarrow$ plotted as freq ω

1.5 μm

interpolate°

photon - disp

pump - disp



interpolct°

how we get the sinc $\left(\frac{\Delta\beta L}{2}\right)$

$\beta_s(\omega_s)$

$\beta_i(\omega_i)$

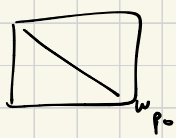
$\beta_p(\omega_s+\omega_i)$

$\omega_p = \omega_s + \omega_i$

Connect° 1st sem (after plot above)

$\omega = \omega_s + \omega_i$

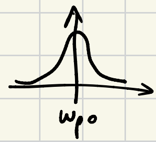
$\omega_s + \omega_i = \underbrace{\omega_{po}}$



fixed it to smth 750nm } changing it moves ↑ or ↓

$\alpha(\omega) \sim$

$\sim exp\left(-\frac{(\omega-\omega_{po})^2}{\Delta^2}\right)$

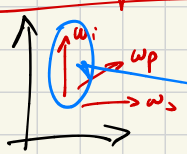


3rd phase

put both plots together

see prev page

How to compute this:



meshgrid: matlab

$\begin{pmatrix} \vdots \\ \omega_s \longrightarrow \\ \vdots \end{pmatrix} \cdot \begin{pmatrix} \omega_i \cdots \\ \downarrow \end{pmatrix} = \begin{pmatrix} \omega_p \end{pmatrix}$

upside down

$\downarrow$ β_s $\qquad$ $\downarrow$ β_i $\qquad$ $\downarrow$ p

$w_s = [ws1, \dots, wsN];$

$w_i = [wi1, \dots, wiM]$

$[S, I] = \text{meshgrid}(w_s, w_i)$

betas = disp(S);

beta i = disp(I);

Beta p = disp-pump(S+I);

phi = sinc-my (Betap - betas - beta i)

don't use the embedded sinc f°

pcolor (S, I, phi)

Correct°

spectrum pump from fem 1

$\approx$

spectrum pump = f° z coordinate

integral in z

eqt° 6 Esenin

evaluate int numerically via (6)

spectrum of alpha ≟ numerical spectrum

20th Feb

Fix x file order

2*pi*c

spline $(\omega, n_{eff}, \omega_s) \to n_{eff}(\omega_s)$

make a starter

photon disper° file wavelength microns 1e-6

$\Rightarrow n_s, n_p, n_i$: meshgrid

make matrix 1st

spline uses matrix

$np = \text{spline}(\ldots, \omega_s + \omega_i)$

Pump (2nd) assume gaussian

alpha $= \exp(-(\omega_s+\omega_i))**2 \cdot t(10**-25)^2 / 10**2$

x reasonable (t_0^2 : duration pulse van's)

$\omega_{p0} = 2\pi c / 780e-9$

central freq pump

Product phi · alpha plot : current chris

Coupling : eqt° (6) $\rightarrow$ get sinc · ep (7)

integrat° by hand

1st exp (6) = pump f° alpha - doesn't depend on z atm

TODO : insert eq (5) → (6)

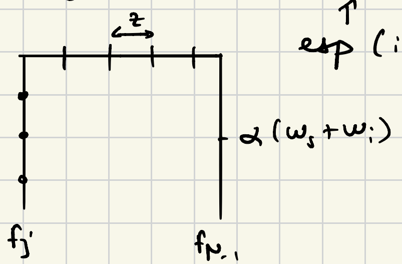
evaluate numerically : trapezium rule in grid z

create a grid of z

waveguide : 3cm

$$\int_0^L f(z)\,dz \approx \sum f_j \,\Delta z$$

$\exp(i\Delta\beta z_j)$



My work 23rd Feb

$$\Phi(\omega_s,\omega_i) = \int_0^L \rho_z \exp\{i\Delta\beta z\}\,dz$$

$$= \left[\rho_z\, i(\Delta\beta)^{-1} e^{i\Delta\beta z}\right]_0^L$$

$$= \rho_z\, i(\Delta\beta)^{-1}\left[e^{i\Delta\beta L} - 1\right]$$

sin$(\Delta\beta^{L/2})$

experiment or sinc → sinc =

$$i\rho_z \frac{e^{i\Delta\beta L/2}\left(e^{i\Delta\beta L/2} - e^{-i\Delta\beta L/2}\right)}{\cancel{\Delta\beta}}$$

plot by modules disapears

$\phi =$ TODO → sinc$(\Delta\beta L/2)\cdot e$

this is why we are not ploting this

should'nt effect shape such should effect vals

7th

$L = z_{max}$

Ultimate goal: eval integral numerically

$$\int_0^L \alpha(\omega_s, \omega_i, z)\, \exp(i\Delta\beta(\omega_s, \omega_i)\cdot z)\, dz$$

↳ become f° of ω_s & ω_i
z disappears

↓ sinc

We are assuming α does not depend on z

• $\alpha(\omega_s, \omega_i) = \exp\left[-(\omega_s + \omega_i - \omega_0)^2/\Omega^2\right]$

plot α v.s sinc

will be replaced with modelling sem 1

We are currently trying to build some confidence in results & thus trying to implement this

Create f° trapezium rule ourselves

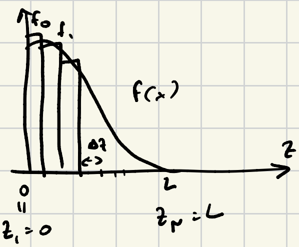
↓

$$\approx \alpha(\omega_s, \omega_i, z_1)\, \exp(i\Delta\beta\cdot z_1)\,\Delta z$$

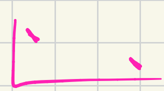
$$+\ \alpha(\omega_s, \omega_i, z_2)\cdot\exp(i\Delta\beta, z_2) + \cdots$$

$$+\ \alpha(\omega_s, \omega_i, z_N)\cdot\exp(i\Delta\beta\, z_N)\cdot\Delta z$$

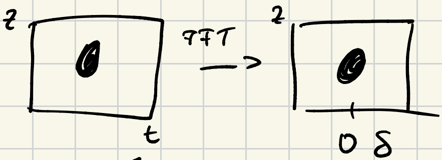
Testing procedure works



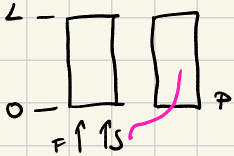
after we implement this we should get two plots



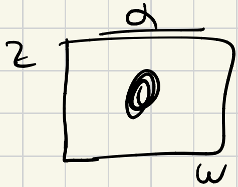
when we are satisfied with result



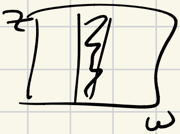
FFT along a certain dimens° of array



↳ this is what we will ultimately have



Now we will have a localised in z result ↳ we are testing for $\alpha(\omega_s, \omega_i)$ not $\alpha(\ldots, \ldots, z)$



← test now!

$$\Delta\beta = \beta_p - \beta_s - \beta_i$$

↑ conserve momentum

leads to $\exp(\Delta\beta t)$

$$\beta_p = \beta_s + \beta_i$$

↑ distinct° around condit°

My work 28th Feb

$$\Phi(\omega_s,\omega_i) = \int_0^L \rho_2 \exp\{i\Delta\beta z\}\, dz$$

$$= \left[\rho_2\, i(\Delta\beta)^{-1} e^{i\Delta\beta z}\right]_0^L$$

$$= \rho_2\, i(\Delta\beta)^{-1}\left[e^{i\Delta\beta L} - 1\right]$$

$$= i\rho_2 \frac{e^{i\Delta\beta L/2}\,\underbrace{\left(e^{i\Delta\beta L/2} - e^{-i\Delta\beta L/2}\right)}_{\sin(\Delta\beta L/2)}}{\Delta\beta}$$

plot by modulus disappears

exponential or sinc

TODO → $\sin(\Delta\beta L/2)\,.\,e$

My work 23rd Feb

$$\Phi(\omega_s,\omega_i) = \int_0^L \rho_2 \exp\{i\Delta\beta z\}\, dz$$

$$= \left\{e^{i\Delta\beta L/2}\rho_2\, i(\Delta\beta)^{-1} e^{i\Delta\beta z - i\Delta\beta L/2}\right\}_0^L$$

$$= \rho_2\, i(\Delta\beta)^{-1}\left[e^{i\Delta\beta L} - 1\right]$$

$$= \frac{i\rho_2\, e^{i\Delta\beta L/2}}{\Delta\beta}\, 2i\,\underbrace{\sin(\Delta\beta L/2)}_{\sin(\Delta\beta L/2)}$$

plot by modulus disappears

exponential or sinc

TODO → $\sin(\Delta\beta L/2)\,.\,e$

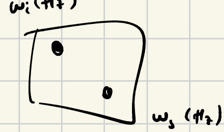
$$= \frac{-2\rho_2\, e^{i\Delta\beta L/2}}{\Delta\beta} \sin\left(\frac{\Delta\beta L}{2}\right)$$

$$= \frac{-\rho_2\, e^{i\Delta\beta L/2}}{L}\, \mathrm{sinc}\left(\frac{\Delta\beta L}{2}\right)$$

As expected

Btw 23rd/2 & 5/3

we implemented the integral & found the expected result

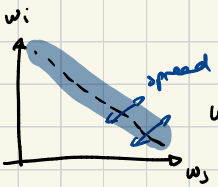


Notes 5th March

line 9 – Pulse.file : correct time domain $10^{-12} \to s$ THz

freq = current freq + ω_0

$\frac{2\pi c}{\lambda_0} \sim 750\,nm$



$\omega_s + \omega_i = \omega_0$

$\omega_0 = \frac{2\pi c}{750\,nm}$

spline interpolat? – be carefull here (check)!

→ trapezium integrat? needs smaller step (t)

both slots are the same reflected

we can close it to a smaller search space – only one slot

^ try make it faster with zoom-in

once this test is completed

correct from prev data

interpolate frequencies prev data with current

length waveguide

- P field appears & disappears

may also need to interpolate in P

change shift propagation code ⟵ see effects on plot

Gorbatch email ← why he thinks problem comes from

Problem
Plot real / img
Fig 2 - fine structure shouldn't exist
Real : period aligns $\frac{\tau_{max}}{2}$ enters ← offset time start
Img — doesn't align

Chris thought fixed - not

Task Purpist - diff variable changes

Notes 21st March

width = Gaussian width → knowing makes our f' change as it did

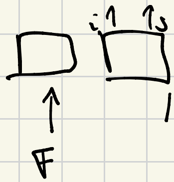
P field : fire street / accross time

TODO: increase resolut° in frequency : time window ↑ & more points

coarser resolut° in time & better resolut° in freq

min, max freq inconsistencies should be resolved

trying to calc joint spectral amplitude

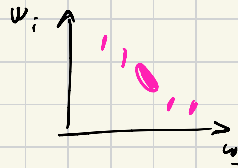


] state described by

$|\psi\rangle = \iint J(\omega_s, \omega_i) |\omega_s\rangle |\omega_i\rangle d\omega_s d\omega_i$

joint spectral amplitude JSA

JSI = $|J|^2$



CASE SCENARIOS
- problem code
- numerical feature
- real feature
- do we not have enough info ?

WE KNOW

$$J(\omega_s, \omega_i) = \int_0^L \alpha(\omega_s, \omega_i, z) \exp(i \Delta\beta_z) dz$$

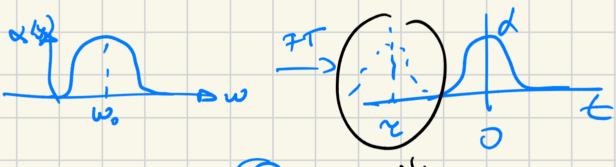
Build confidence our code is building this exactly

STEPS

① If $\alpha(\omega_s, \omega_i)$ does not depend on z, we know the answer (analytically)

$$\alpha(\omega_s, \omega_i) = \exp\left(-\frac{(\omega_s + \omega_i - \omega_0)^2}{\Omega^2} \right) = L\,\alpha(\omega_s, \omega_i)\,\text{sin}(\Delta\beta L)$$

checked with our numerics



② Fourier transfer shifted gaussian

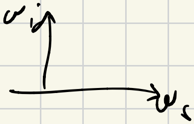
$$\alpha(\omega_s, \omega_i) = \exp\left[\frac{-(\omega_s + \omega_i - \omega_0)^2}{\Omega^2} \right] \exp\left(i(\omega_s + \omega_i)\tau\right) \quad \text{with } |\alpha_1| = |\alpha_2|$$

our pulses are not centered - so we could be working with a shift → could be causing the effect

shifting in time analytically shouldn't change anything

but does it change in our analytic?

TODO: test: change τ → is there a difference in ω_i ?



↓

difference → problem

non - difference → our structure may be due to something more subtle than time shift

continue todo:

- take max seed² at max
- see if shift affects other stuff

GOAL: ~~DO~~ THE CODE WORKING CORRECTLY

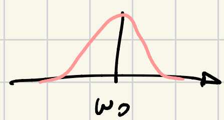
↓ then

optimise

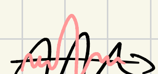
↑

what do we want?

$|\omega_0\rangle$ = photon with well defined frequency



can't know about lifetime: ∞ wave oscillating

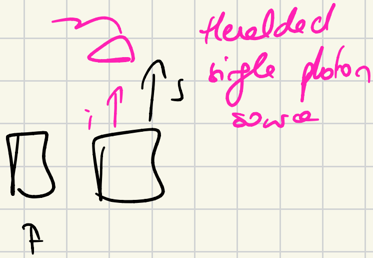


realistic localised photon

single photon = $|\psi\rangle = \int A\, |\omega_s|\omega\rangle\, d\omega$: superposition ideal photons but we have a state of two photons → trying to understand JSA

analogous to $|\psi\rangle = \int A(\omega)|\omega\rangle d\omega$ in a single photon

ultimate goal device: source single photons



we get spontaneous $\underbrace{\text{joint pairs}}$ at diff frequencies

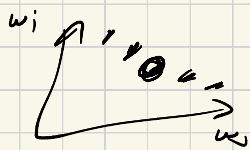
ranges: $\omega_i \neq \omega_s$

here a detector to a specific freq

kill i: convert electric current

now we only have 1 photon

trying to always produce the same pair (keep one / kill the other) is hard

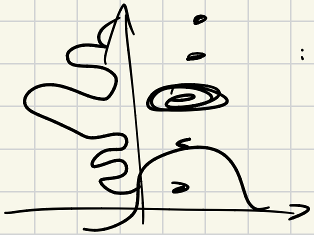


← won't be easy to get constant ω_i & ω_s

in order to make i & s indep (so when we destroy i we always get the same s)

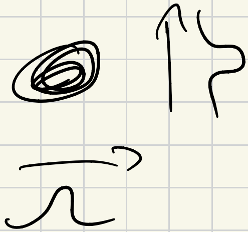
↓

we want to be separable: $J(\omega_s, \omega_i) = I(\omega_i) \cdot \underbrace{S(\omega_s)}_{\text{will describe output photon}}$

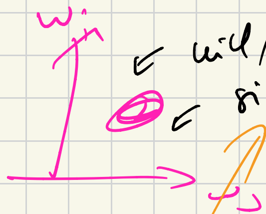


: if it comes at an angle it is no longer seperable

seperable :



Good optimiser?:



← will/minimize

← sidelobes

will not be perfect but "looks better"

single variable decomposit^n : "good" way to check this is a seperable function