Lab Work
CPT-based Cs microcell Atomic Clock

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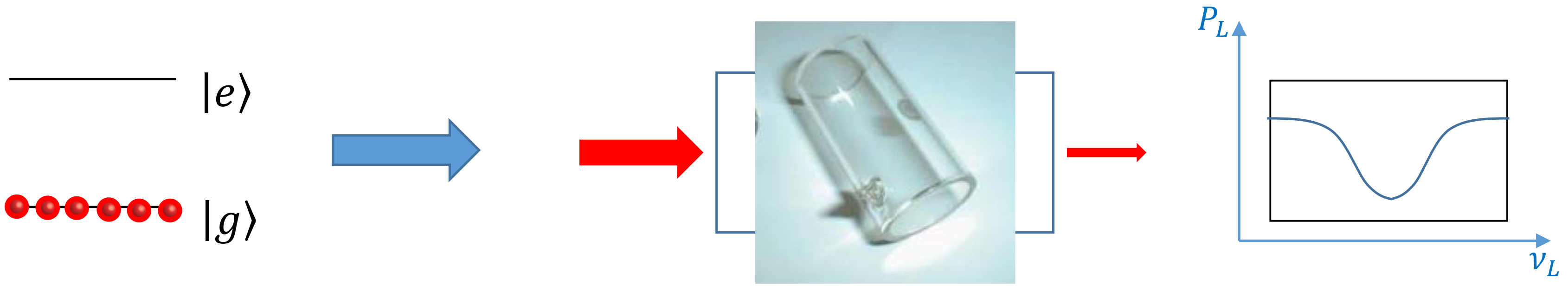
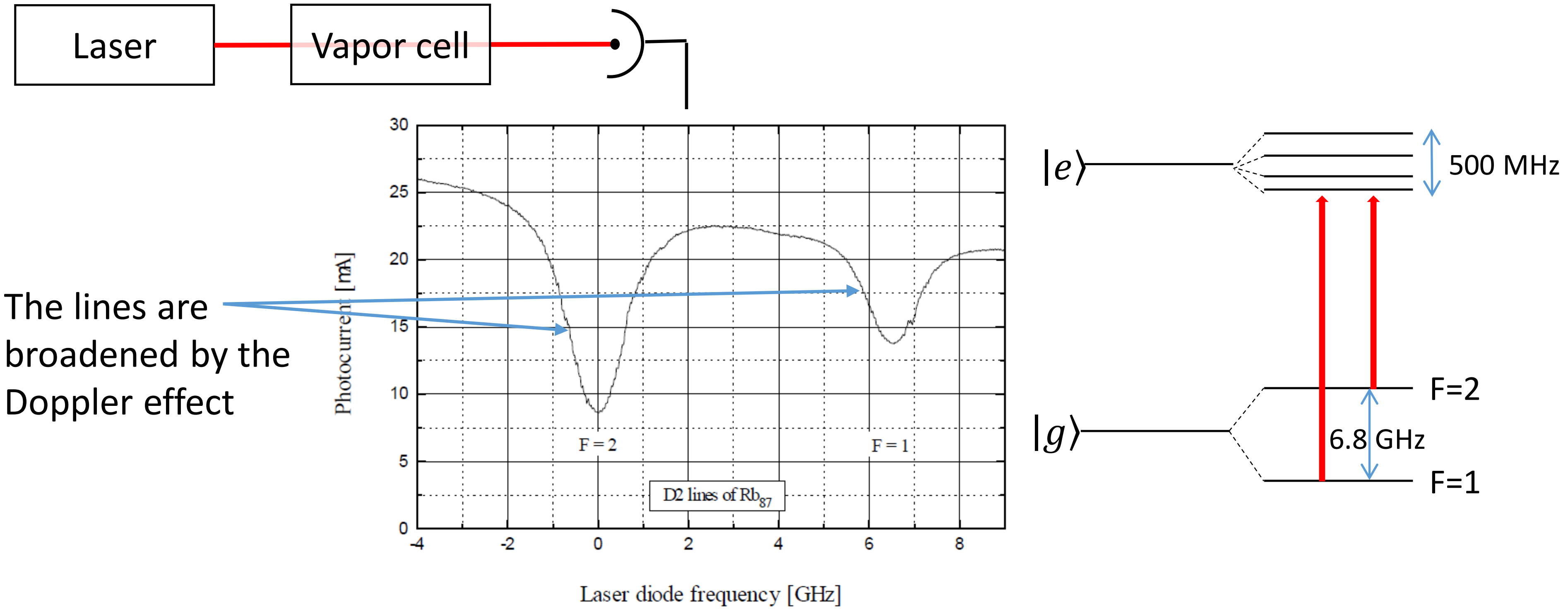
Reminder: Linear Spectroscopy (cf. Mileti, Lacroûte)



Very easy! Put a gas vapor in a glass cell!

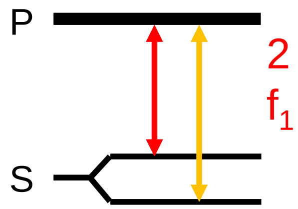


The lines are broadened by the Doppler effect

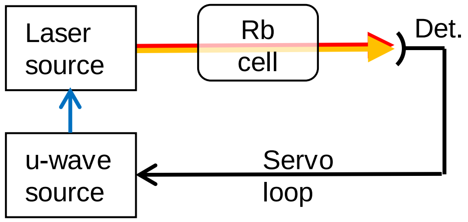
Reminder: CPT in cell clocks (cf Mileti, Affolderbach)

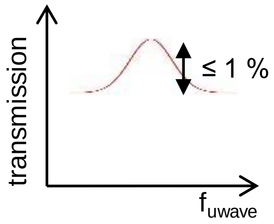
Coherent Population Trapping (CPT)

2 coherent light fields,
Simultaneous preparation and interrogation



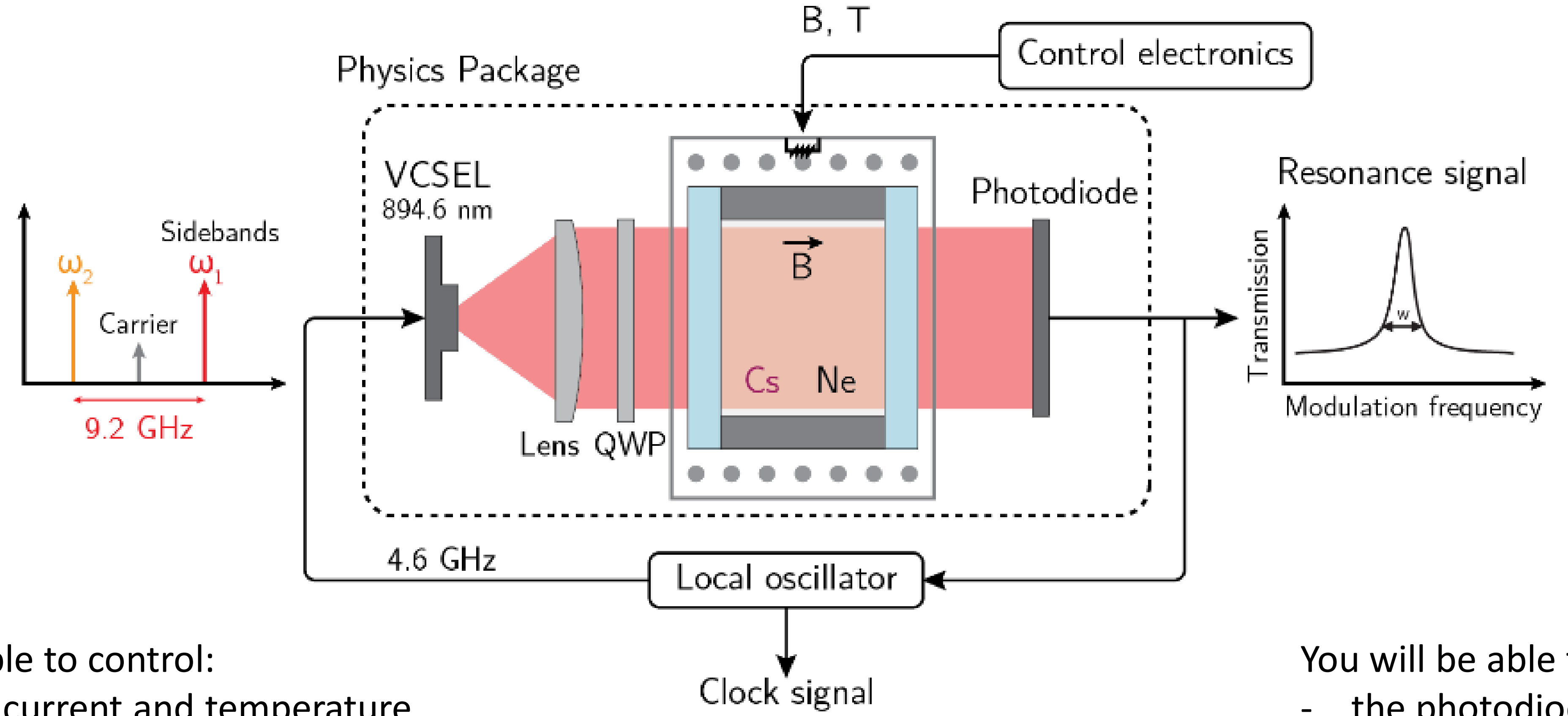
2 light fields:
$f_1 - f_2 = f_{HFS} = f_{clock}$





- Employs coherent laser effects
  ⇒ potential for new & improved clocks
  (first proposal: Cyr et al., IEEE TIM, 1993)
- No microwave cavity needed
  ⇒ more radical clock miniaturization

Lab work CPT clock



You will be able to control:

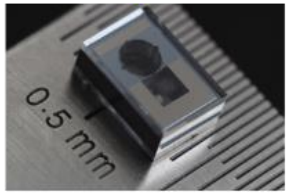
- the VCSEL current and temperature
- the magnetic field
- the local oscillator frequency
- the RF modulation power

You will be able to view:

- the photodiode signal
- laser and local oscillator error signals
- the clock signal

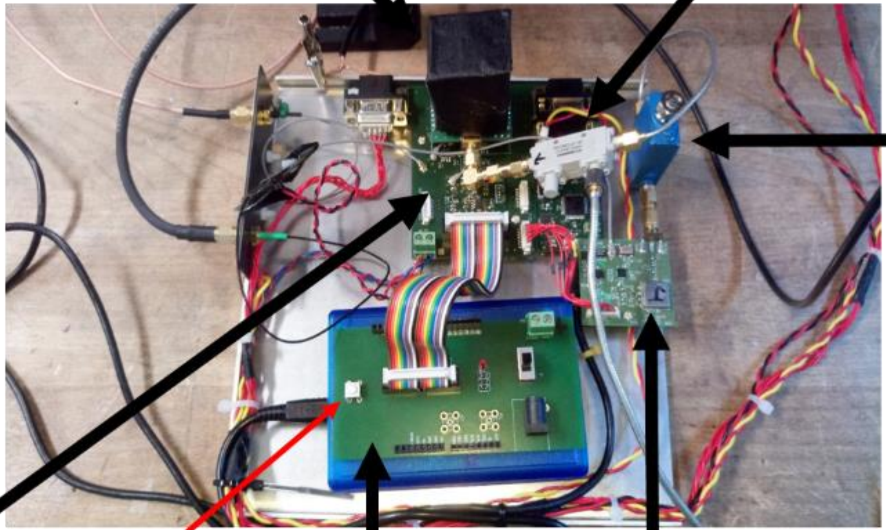
Lab work CPT clock – hardware

Physics package box
(VCSEL+ optics + Cs-NeMicrocell + photodiode)
Heating elements + Sensors + B-field wire+ Magnetic shielding



Cs-Ne microcell

Microwave coupler
(to monitor the 4.6 GHz signal)



Microwave attenuator
(manual) to tune the 4.6 GHz
power

Embedded
electronics

Loops reset

Arduino

Local oscillator
(4.6 GHz VCO phase locked to
a 10 MHz quartz oscillator
using a N-fractional PLL)

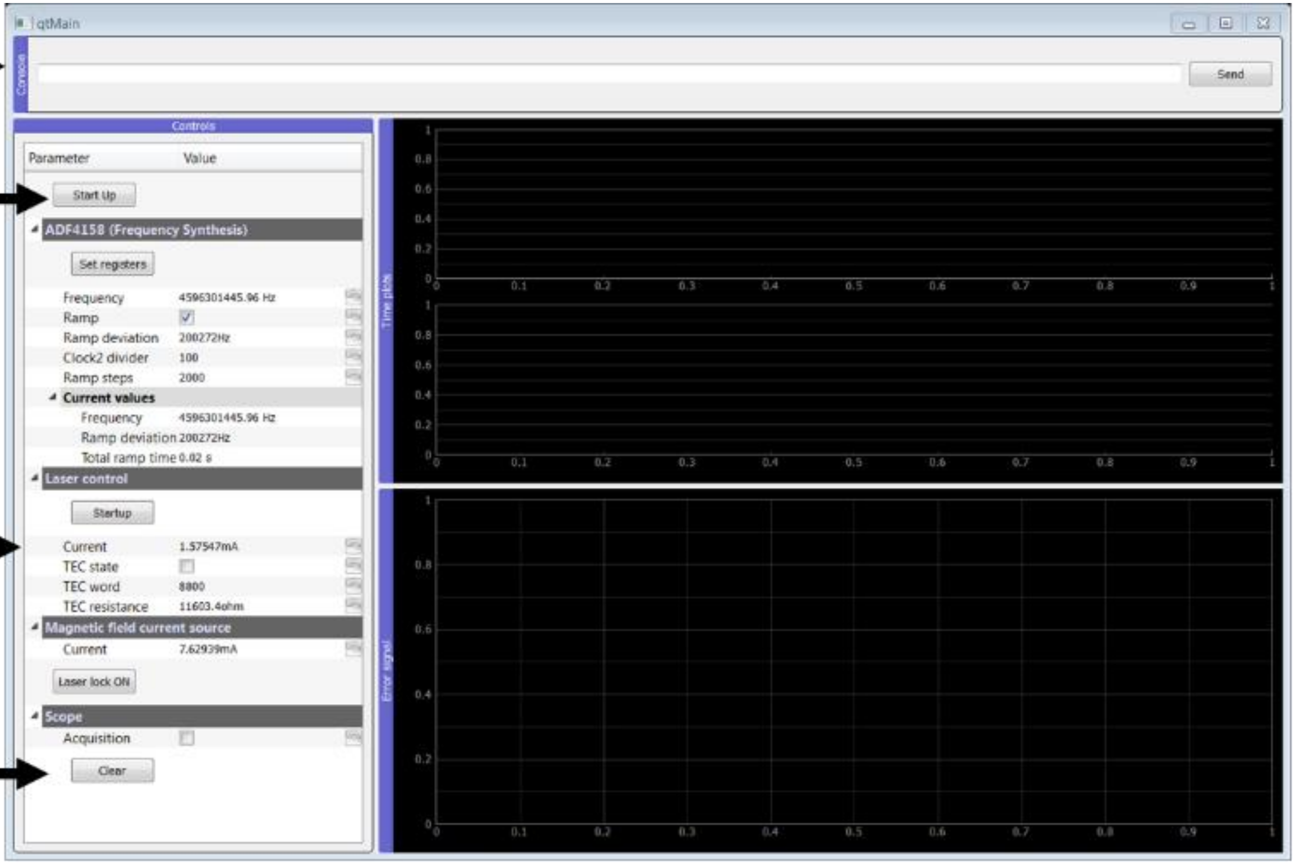
Lab work CPT clock – software

Enter serial commands here

Startup to initialize parameters (set the register of PLL ADFxx)

Set the laser current here

Clear the last scope acquisition (use it before each new CPT scan)



PhD output mean signal

Servo error signal

CPT error signal scan window

The whole experiment is controlled by an Arduino controller, interfaced using a C software and a Python interface.
The GUI lets you input the commands as digital words within the command line.
Some parameters (laser diode current, magnetic field current) can also be input in their proper unit in the dedicated boxes.
You can view the commands and digital words actually sent to the micro-controller in the command window

Lab work CPT clock – what you will do

1 – Characterize the laser diode

2 – Linear spectroscopy

3 – CPT signal

4 – Lock the LO using the CPT signal

5 – Characterize the clock frequency stability

You may now start the lab work… by reading the printed labwork subject!

CPT linewidth – influence of collisions

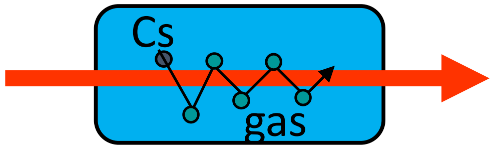
Buffer-gas: avoids ground-state relaxation by collisions with the cell walls.

Diffusion: $\Gamma_{\text{diff}} = 2\left(\frac{\pi^2}{L^2} + \frac{2.405^2}{R^2}\right) D_0 \frac{p_0}{p} \left(\frac{T}{T_0}\right)^{3/2} \propto \frac{1}{p}$ Collisions with the walls

Collisions: $\Gamma_{\text{coll}} = 2\, n_{\text{buff}}\, \sigma_{\text{coll}}\, \bar{v}_{\text{rel}} \propto p$ Collisions with the buffer gas

Spin-exchange coll. $\Gamma_{\text{se}} = 0.6875\, \bar{v}_r n_{\text{Cs}} \sigma_{\text{se}} \propto p_{\text{Cs}}$ Cs-Cs collisions

Total: $\Gamma_{12} = \Gamma_{\text{diff}} + \Gamma_{\text{coll}} + \Gamma_{\text{se}}$



$\Rightarrow$ Compromise on p, p_{Cs} => optimal T for a given cell (ie Cs + buffer gas mixture)
$\Rightarrow$ T, p, p_{Cs} are crucial parameters

Linear absorption – linewidth

The total width of absorption lines Γ^{*} is determined by:

$$\Gamma, \beta p, \Delta\nu_D$$

Natural width

Collisional broadening (MHz/Torr)

Pressure

Doppler width

with $\Delta\nu_D = \frac{2\nu_0}{c}\sqrt{\frac{2\ln(2)kT}{m}}$ where *k* is the Boltzmann constant, *T* is the temperature and *m* is the atom mass.

Linear absorption – linewidth

The total width of absorption lines Γ^* is determined by:

$$\Gamma, \beta p, \Delta\nu_D$$

4,56 MHz

10-20 MHz/Torr

Pressure

Approx.
360 MHz
@295 K

with $\Delta\nu_D = \frac{2\nu_0}{c}\sqrt{\frac{2\ln(2)kT}{m}}$ where *k* is the Boltzmann constant, *T* is the temperature and *m* is the atom mass.

Linear absorption – linewidth

The total width of absorption lines Γ^* is determined by:

$$\text{Lorentzian} \longleftarrow \Gamma, \beta p, \Delta\nu_D \longrightarrow \text{Gaussian}$$

In practice, the line profile is a Voigt function (convolution of Gaussian and Lorentzian) from which one can extract both the temperature and the pressure broadening.

Linear absorption – linewidth

The total width of absorption lines Γ^* can be roughly approximated by:

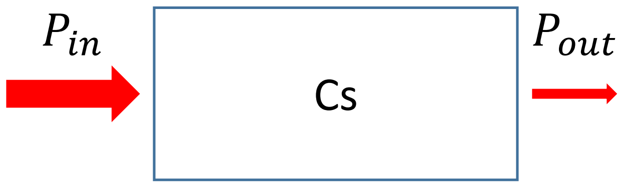
$$\Gamma^* \approx \frac{\Gamma + \beta p}{2} + \sqrt{(\Gamma + \beta p)^2/4 + \Delta\nu_D^2}$$

From a fit, one could extract *T* and β or *p.*
Here, we know *T* and β so we can deduce *p*.

A better approximation (0.02% error – source Wikipedia):

$$f_V \approx 0.5346 f_L + \sqrt{0.2166 f_L^2 + f_G^2}.$$

Linear absorption – Beer-Lambert law



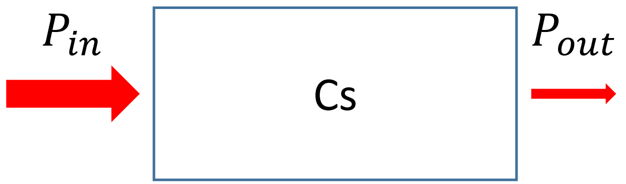
$$P_{out} = P_{in} \exp(-\alpha L)$$

where L is the cell length and α is the absorption coefficient given by

$$\alpha = \frac{\Gamma^* \lambda^3 n_{cs}}{8\pi} \sqrt{\frac{m}{2\pi k T}}$$

where n_{cs} is the Cs density inside the cell, and λ is the line wavelength.

Linear absorption – Beer-Lambert law



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Here we know T and Γ^* so we can deduce n_{cs} *ie* p_{Cs}.

In summary:

Here we know *T, L* and β;

by measuring the optical linewidth Γ^* and absorption α we can deduce the buffer-gas pressure p and the Cs pressure p_{Cs}

$\Rightarrow$ rough estimate of expected CPT linewidth