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# Optical Pumping Experiment

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# Outline

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- Background Theory for optical pumping  
(Presented by Kiseok Chang)
- Instruments and Experimental Procedure  
(Presented by Zhensheng Tao)
- Experimental Results  
(Presented by Kyaw Zin Latt)

# Introduction

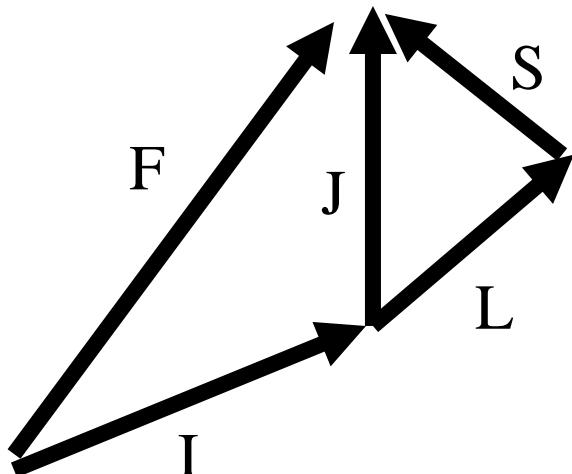
## □ Why do we use Rubidium atom?

Rubidium Alkali atom ;  $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 5s$

The simplest atomic structure like hydrogen for our optical pumping experiment.

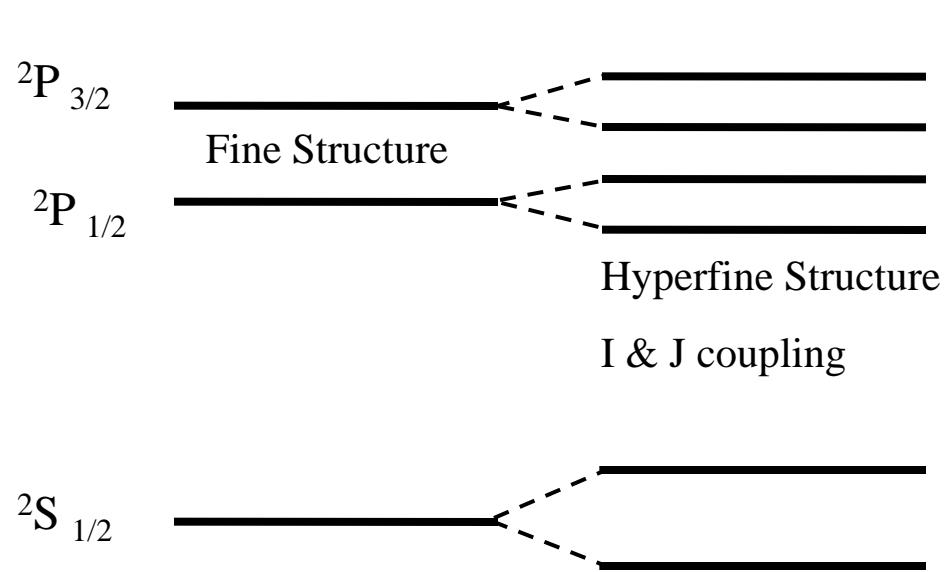
Electronic state:

total angular momentum  $J = L + S$



Nuclear spin state ( $I$ ):

total angular momentum  $F = J + I$



# Zeeman Effect

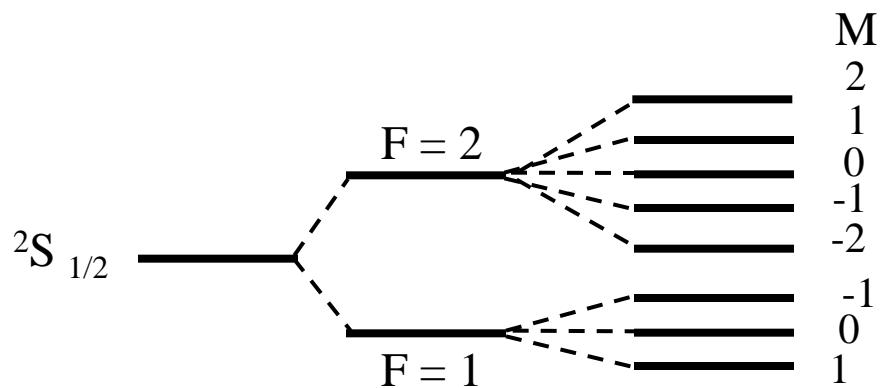
$$H = \hbar I \cdot J - \frac{\mu_J}{J} J \cdot B - \frac{\mu_I}{I} I \cdot B$$

Energy difference varies with external field. Using this property, we can measure the energy difference.

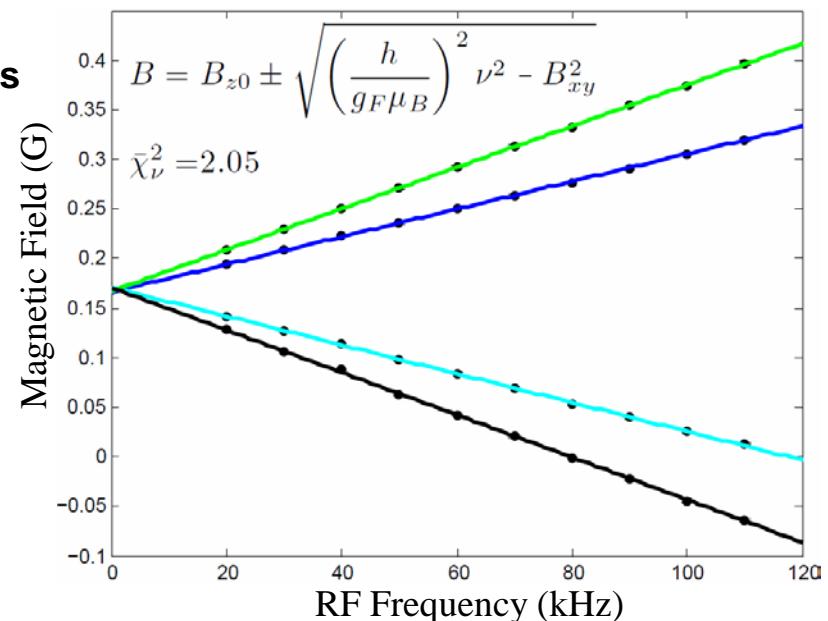
$$B = B_0 + \frac{\hbar}{g_F \mu_B} \nu$$

$$g_F = g_J \frac{F(F+1) + J(J+1) - I(I+1)}{2F(F+1)}$$

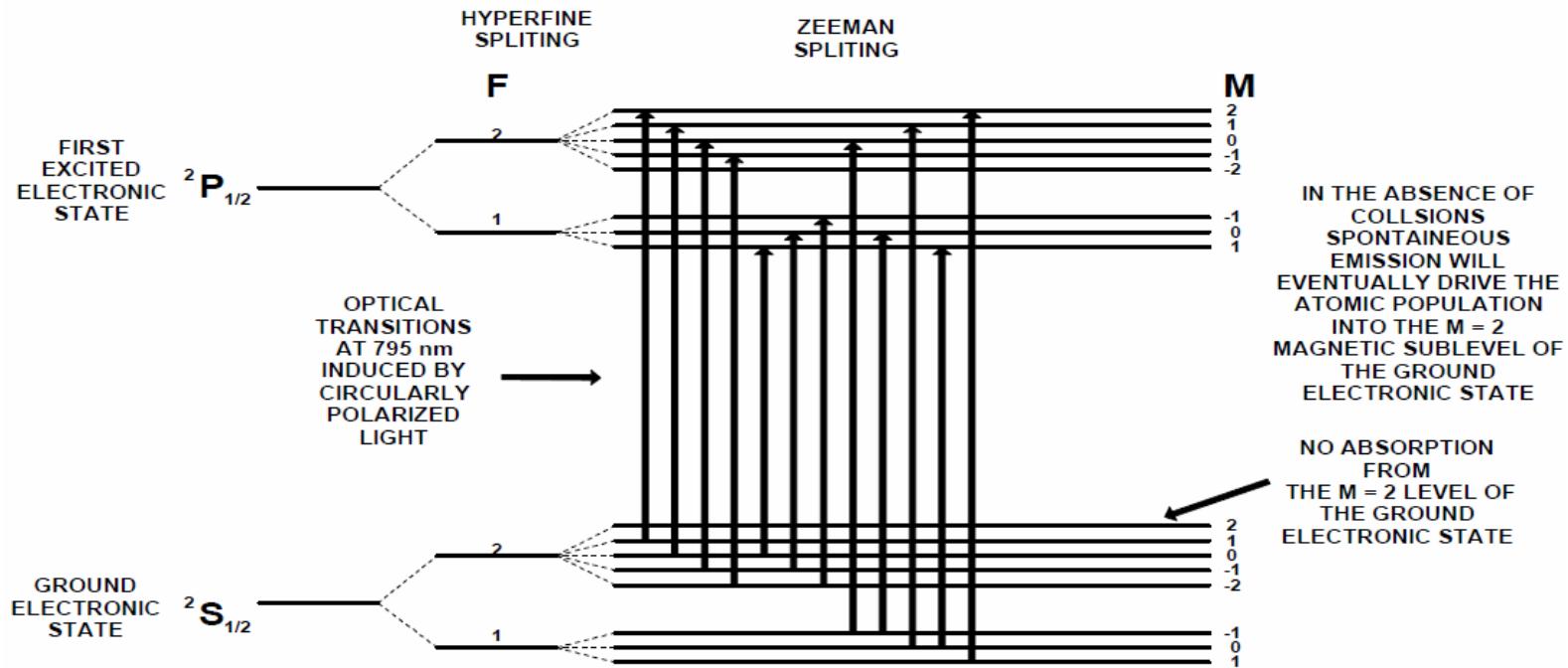
$$g_F(^{85}Rb) = \frac{1}{3} \quad g_F(^{87}Rb) = \frac{1}{2}$$



- 1) Controlling the external B-field
- 2) Controlling RF field



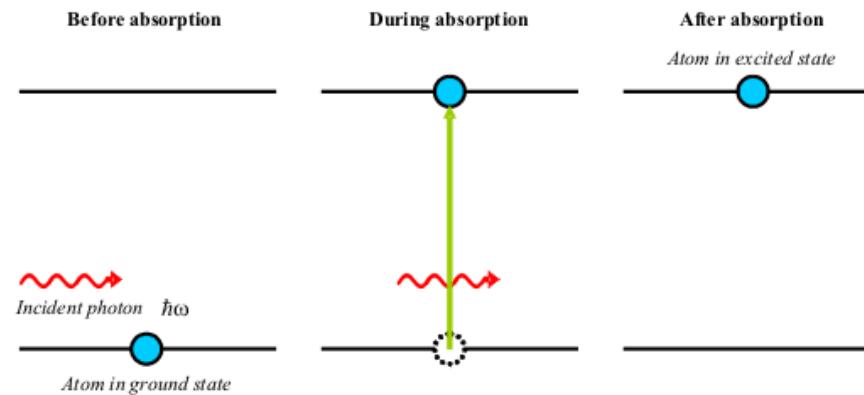
# Optical Pumping



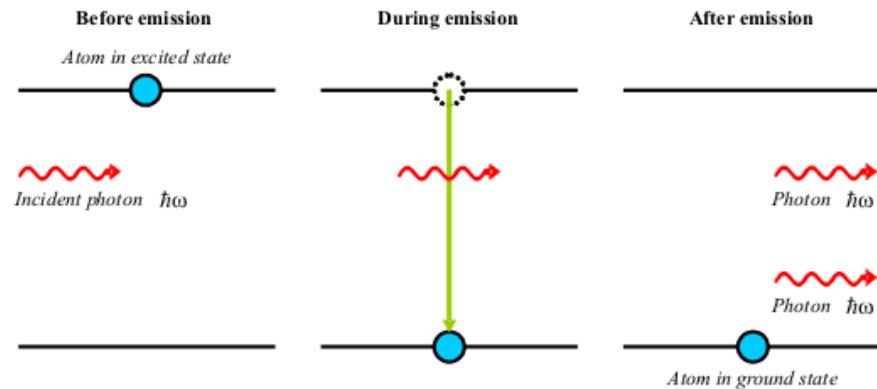
- Circularly polarized photon( $+h/2\pi$ ) drives the transition from  $^2S_{1/2}$  to  $^2P_{1/2}$  with  $\Delta m_f = 1$  (selection rule).
- Spontaneous emission causes  $\Delta m_f = 0, +/ - 1$  transition.
- If atoms reach  $m_f = +2$  in  $^2S_{1/2}$  state, then the atoms are stuck in that state. Thus, population of atoms are pumped to  $^2S_{1/2}$  state.

# Rabi Oscillation

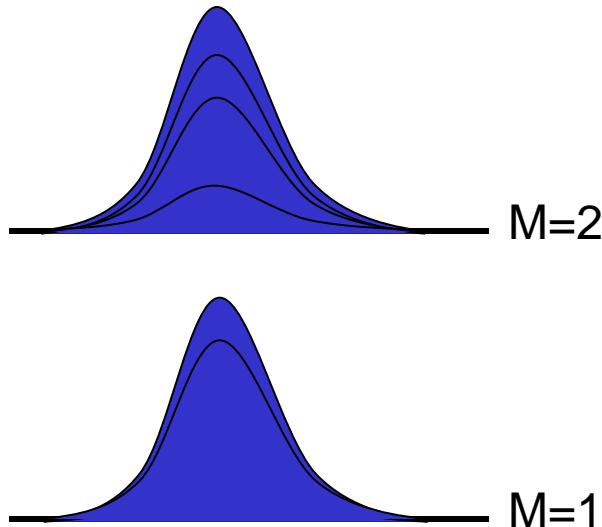
## 1. Excited atom creation



## 2. Stimulated emission



## 3. Emission and re-absorption

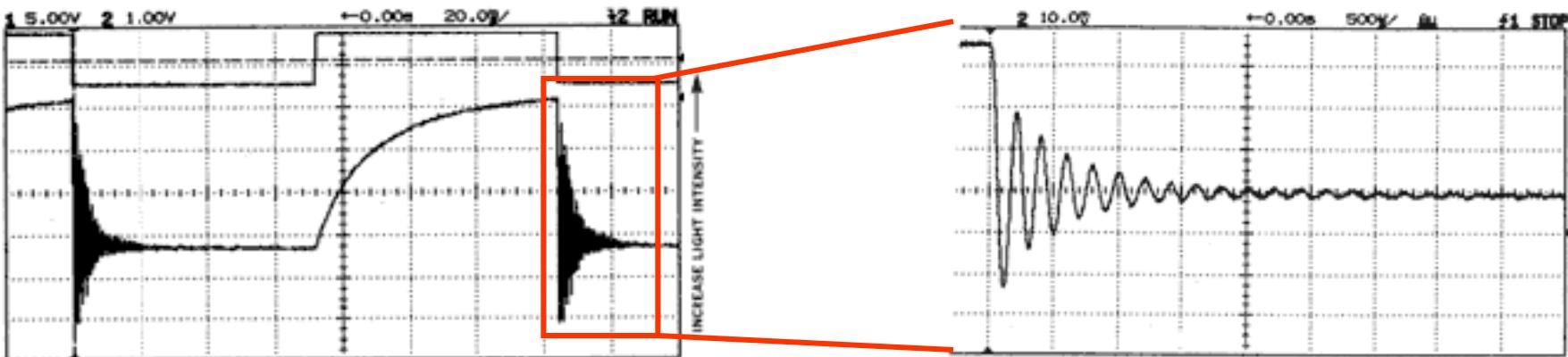


$$P_M = \cos^2(\omega t)$$

$P_M$  : Probability at M state

$\omega$  : Rabi frequency

# Rabi Oscillation



— M=2

1. Using optical pumping, all the atoms are excited in  $M = +2$  state.

$$P_1 = \frac{1}{2} - \delta \cdot e^{-2T_{12} \cdot t}$$

$$P_2 = \frac{1}{2} + \delta \cdot e^{-2T_{21} \cdot t}$$

— M=1

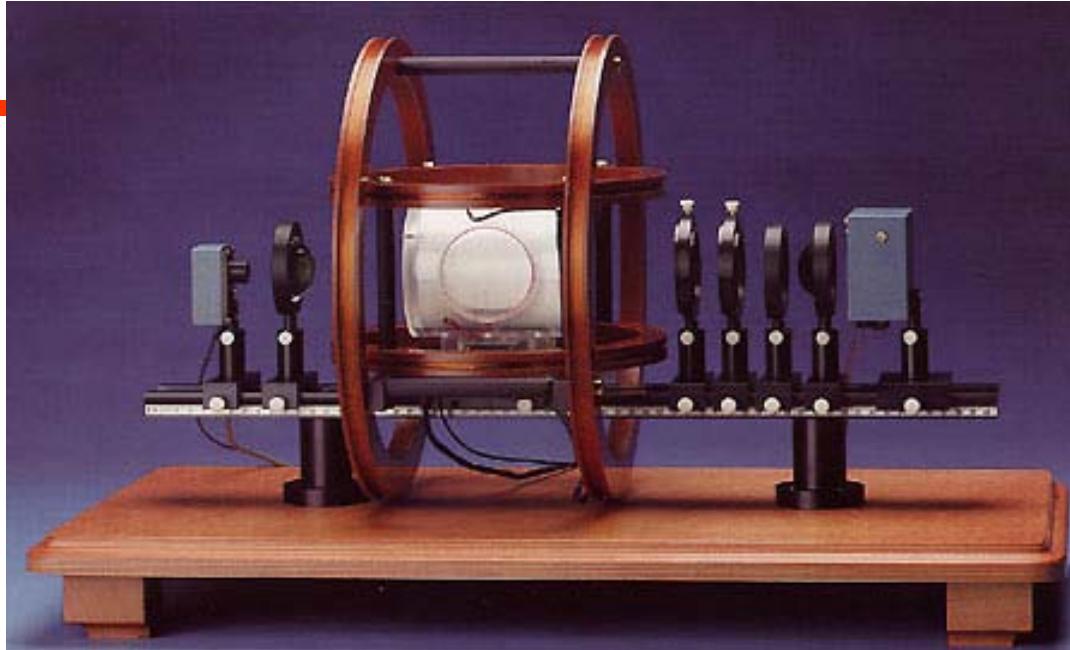
$\delta$  : Excess charge population ;  $T_{12}$  : Transition Probability

2.  $M=2$  state excess population is transferred to  $M=1$  state with decreasing transmitted light intensity.

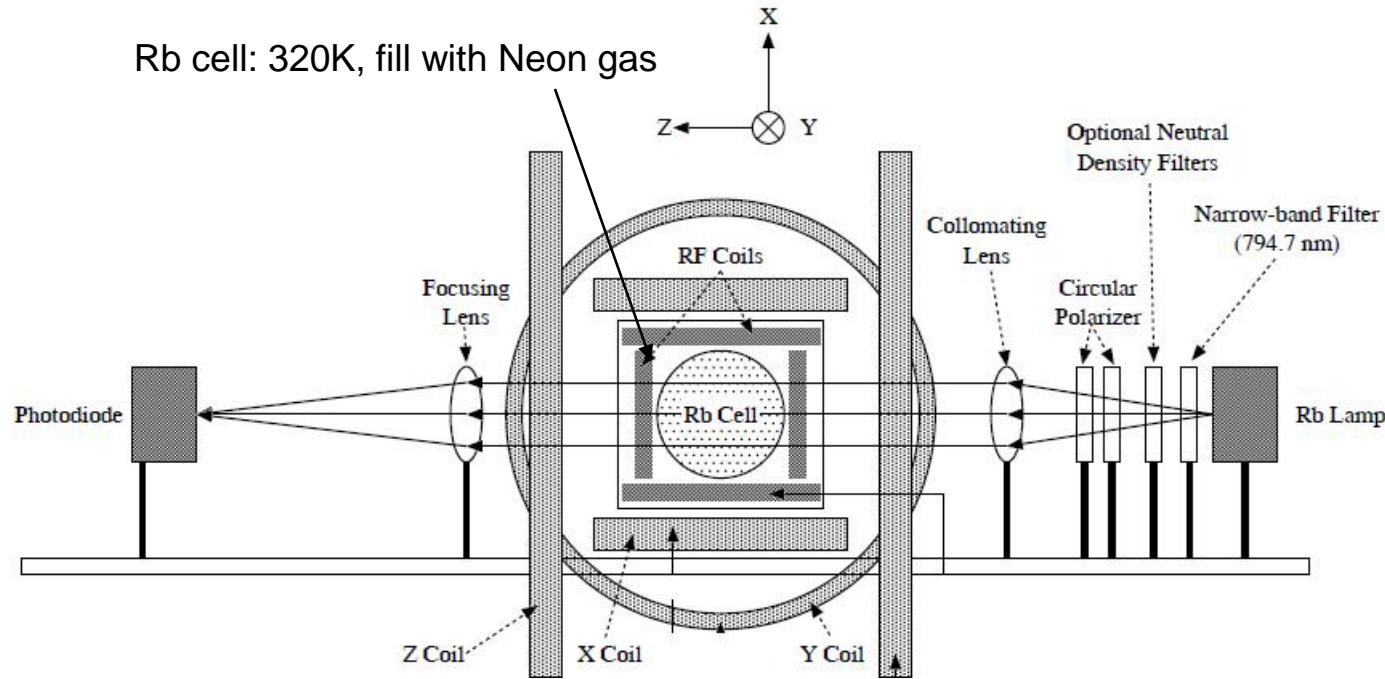
3. Due to stimulated emission, the population inversion is reached with increasing transmitted light intensity.

# Instrument

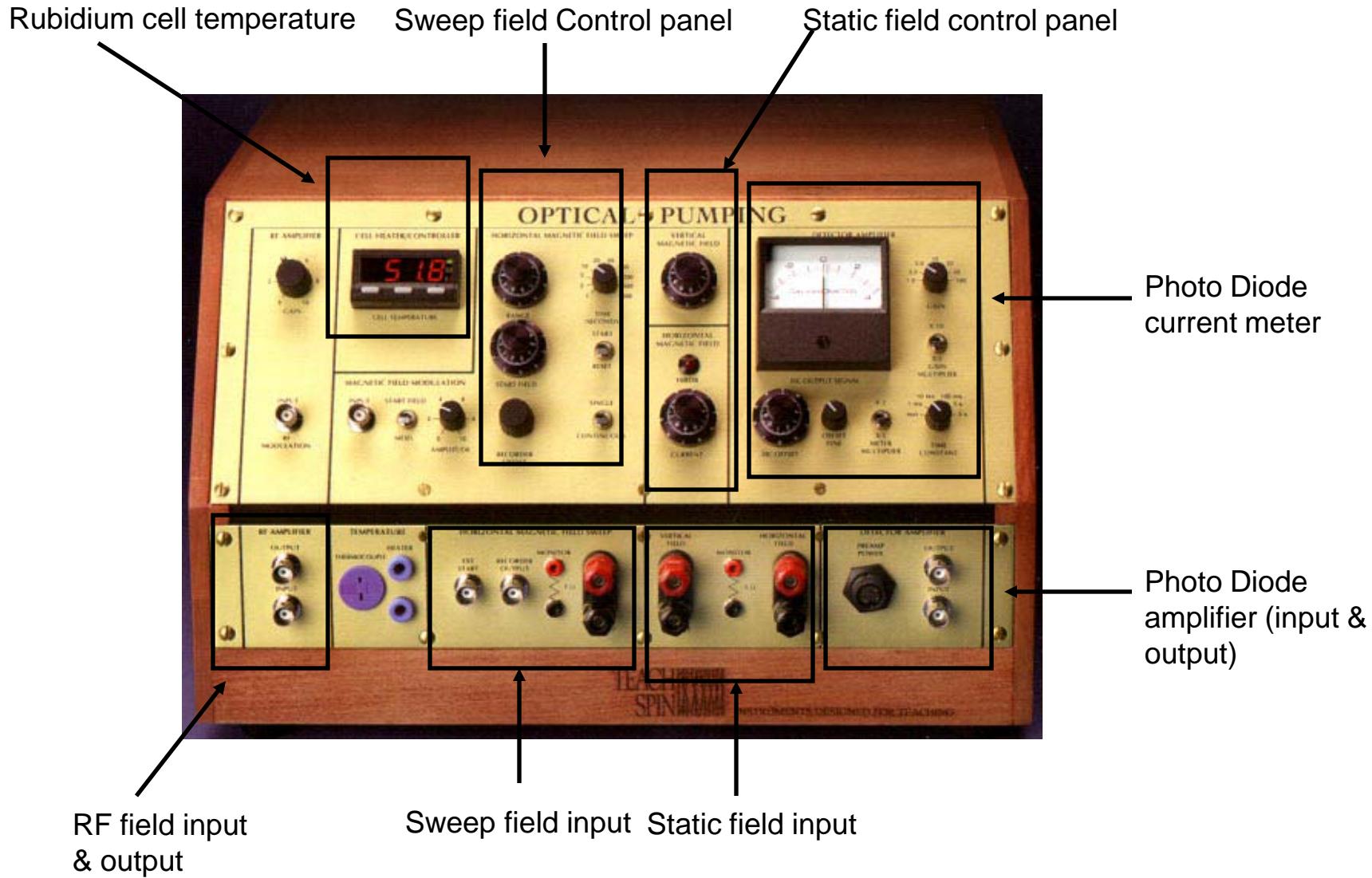
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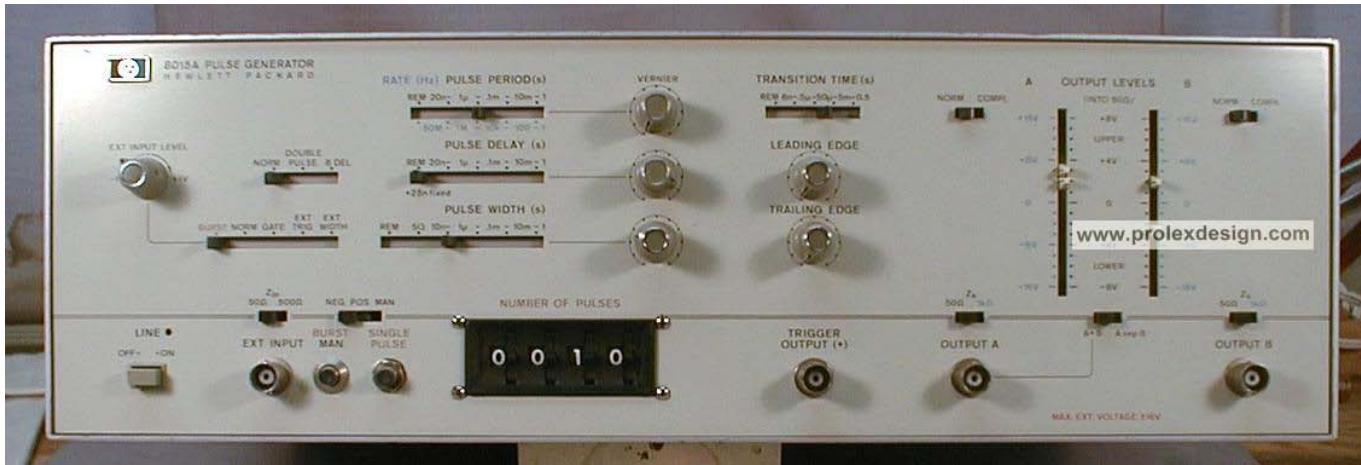
Rb cell: 320K, fill with Neon gas



# Integrated Optical Pumping Controller

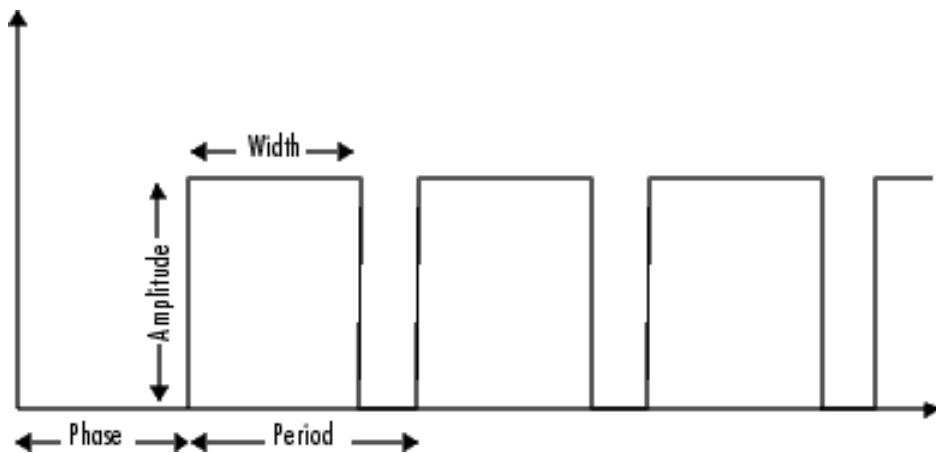


# HP 8015A Pulse Generator



## HP 8015A Pulse Generator

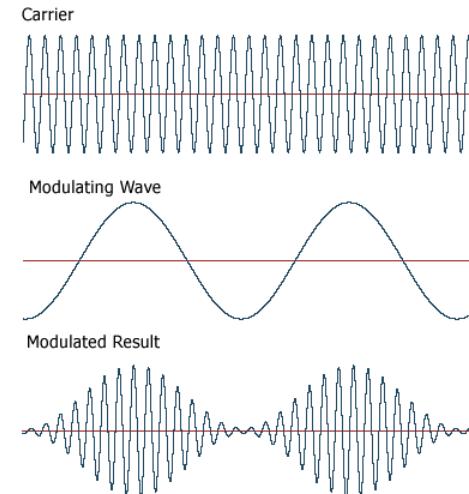
Signal Example:



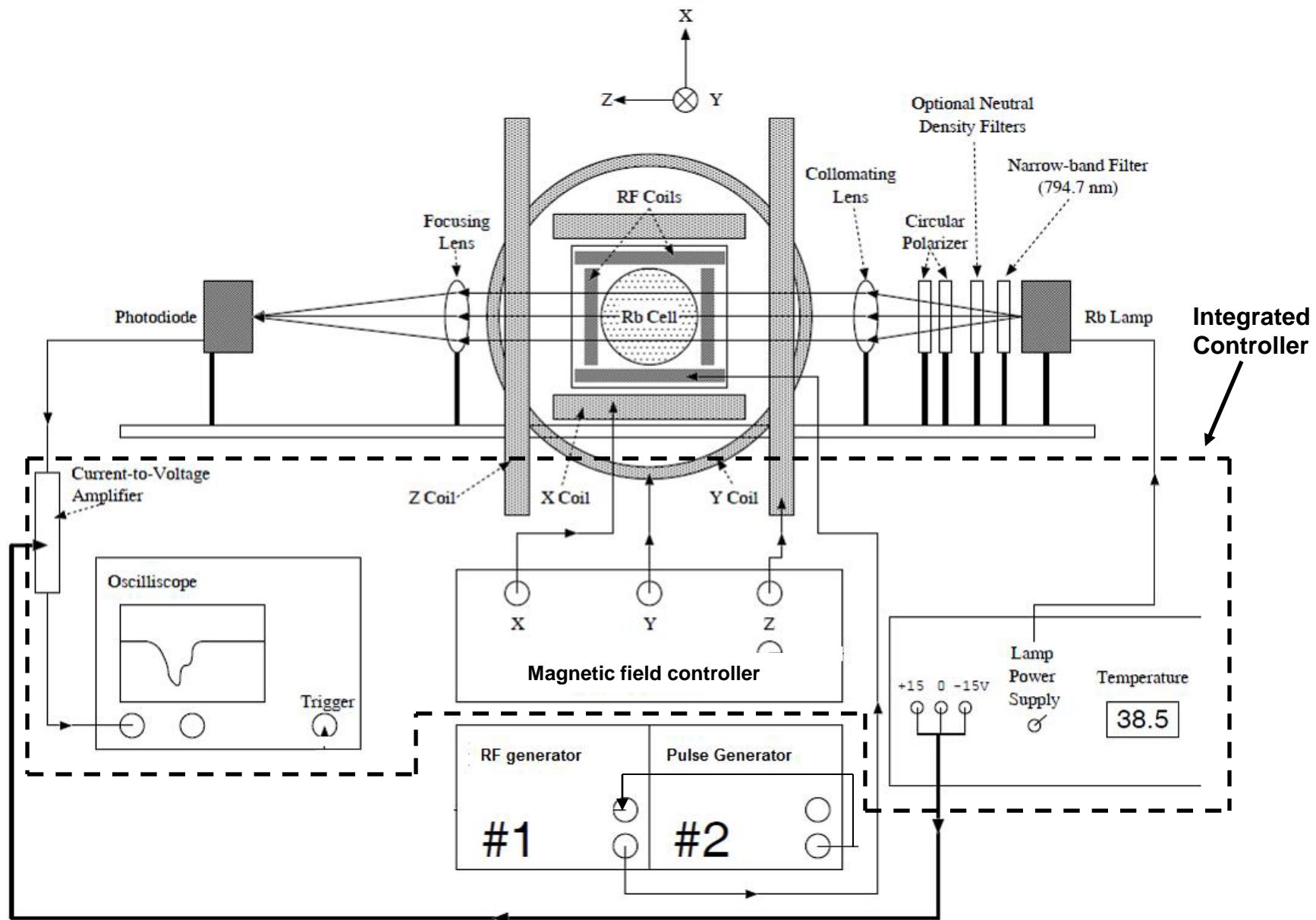


Fluke 6060A Synthesized Signal Generator  
Covering 100kHz to 1050MHz range  
Output level: -137dBm~+13dBm

Signal Example:



# Connection Diagram

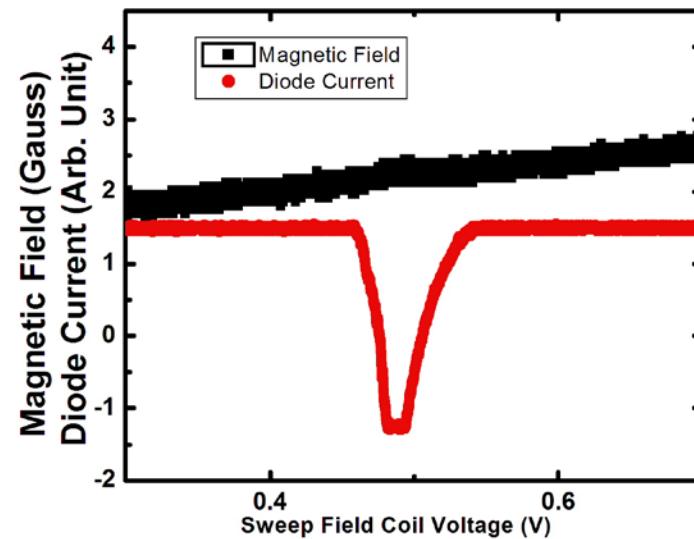


# Experimental Procedure

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## Zero field Resonance:

1. Place the apparatus along the earth magnetic field.
2. Setup the optical path properly. Cover with black box.
3. Heat the Rubidium cell to 320K.
4. Scan the sweep field and plot the curve optical detector signal vs. sweep field voltage in a very slow rate
5. Adjust the orientation of optical stage and vertical static field to make the curve as narrow as possible. (Earth field canceling)

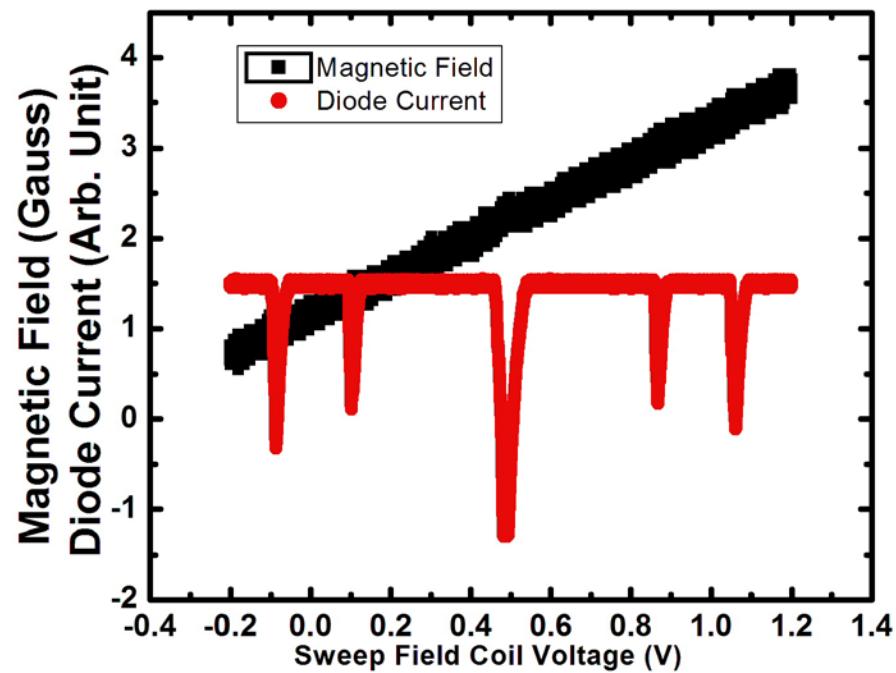


# Experimental Procedure

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## Low Field Zeeman Effect:

1. Cancel the earth field by narrowing the zero field resonance peak
2. Turn on the RF generator and tune the RF frequency from 10kHz to 90kHz
3. Change the sweep field and obtain the absorption dependence on sweep field strength under different RF frequency

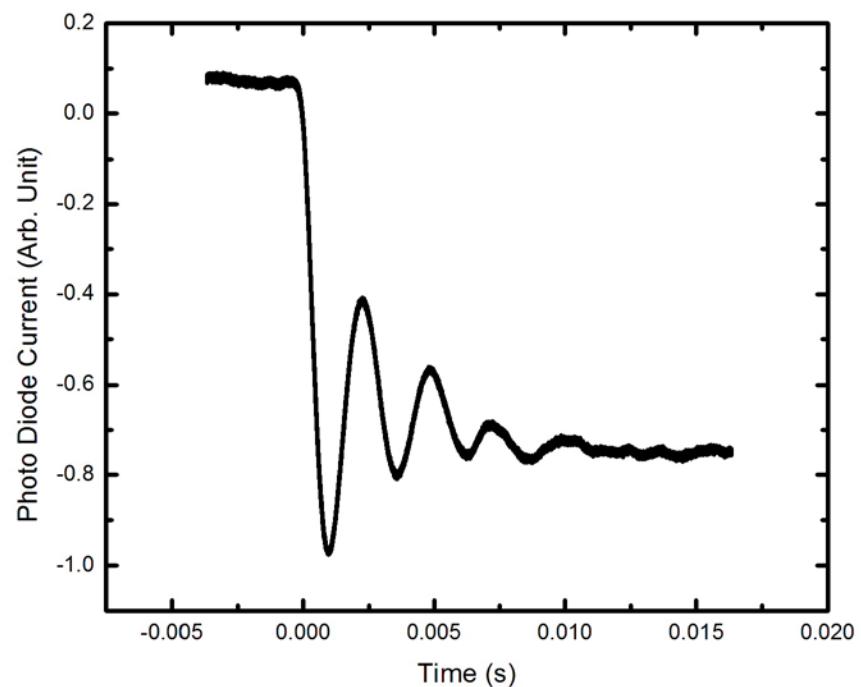


# Experimental Procedure

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## Transient effect (Rabi Oscillation):

1. Adjust the horizontal field or sweep field to make the system at the absorption peak of Rb<sup>87</sup> or Rb<sup>88</sup> by looking at the oscilloscope.
2. Switch on the pulse generator. Use the pulse generator's signal as the trigger to turn on or off the RF signal periodically.
3. Look at the oscilloscope and tune the frequency of pulse generator to make the whole oscillation appear in the screen.
4. Change the amplitude of RF field and record the oscillation curves.



## Sweep field calibration:

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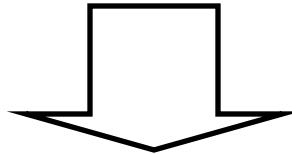
Voltage       $\longrightarrow$       Magnetic field strength  
Coefficient

No Gauss meter ...

Use the horizontal field to calibrate the sweep field

Horizontal field voltage (V)	Sweep field Voltage (V)
0.01228	0.0137
0.00145	0.3164

The coefficient of horizontal field is 88 Gauss/V (Manual)



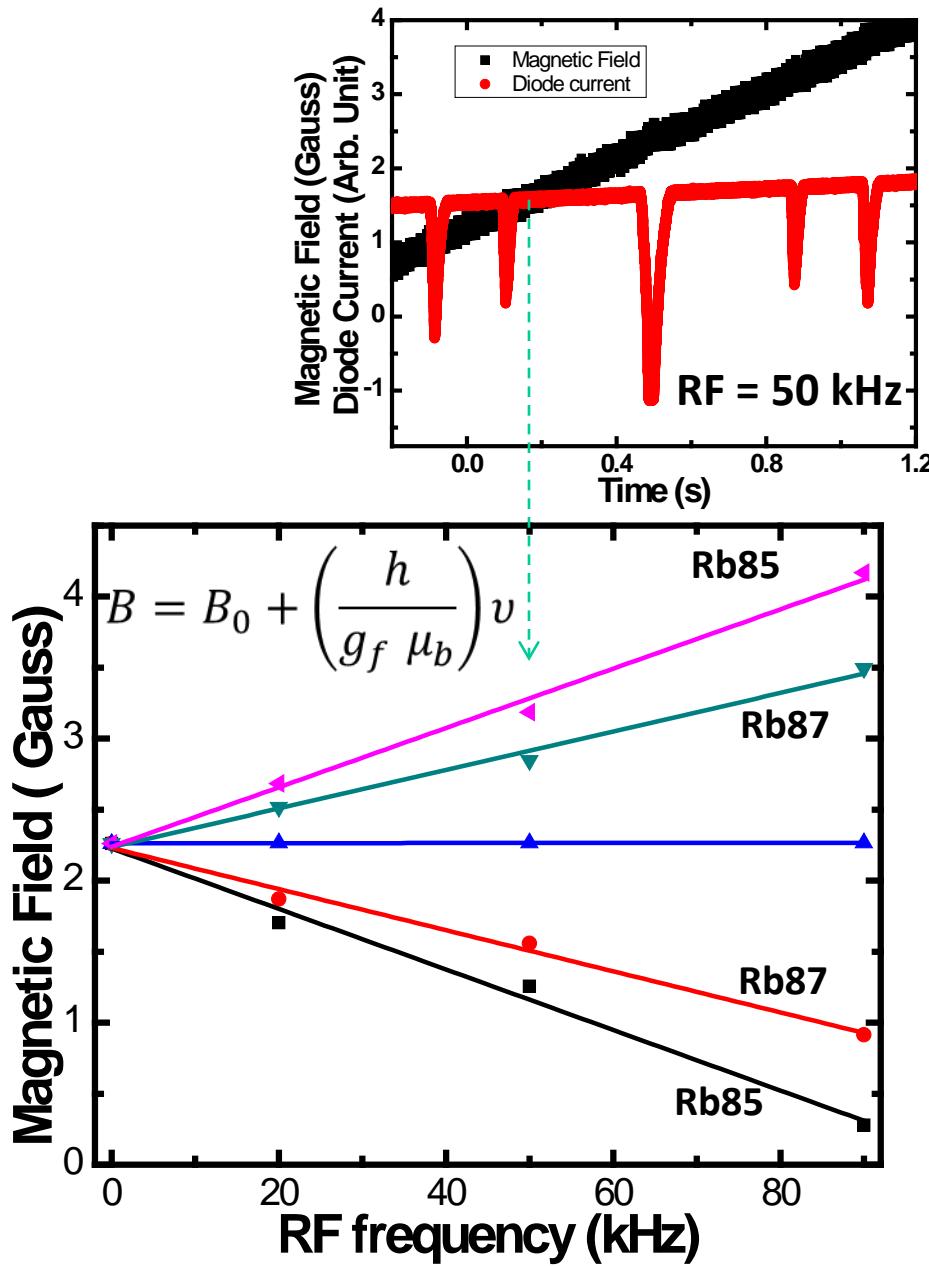
The coefficient of sweep field is 3.167 Gauss/V  
6 Gauss/V on manual

# Experimental Results

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1. Measuring gyromagnetic ratio from Zeeman splitting data
2. Extracting Rabi's oscillation frequency from transient effect
3. Comparing experimental and theoretical Rabi's oscillation frequencies

# Zeeman splitting



$$\text{Slope} = \frac{h}{g_f \mu_b}$$

$$\mu_b = \frac{e \hbar}{2 m_e}$$

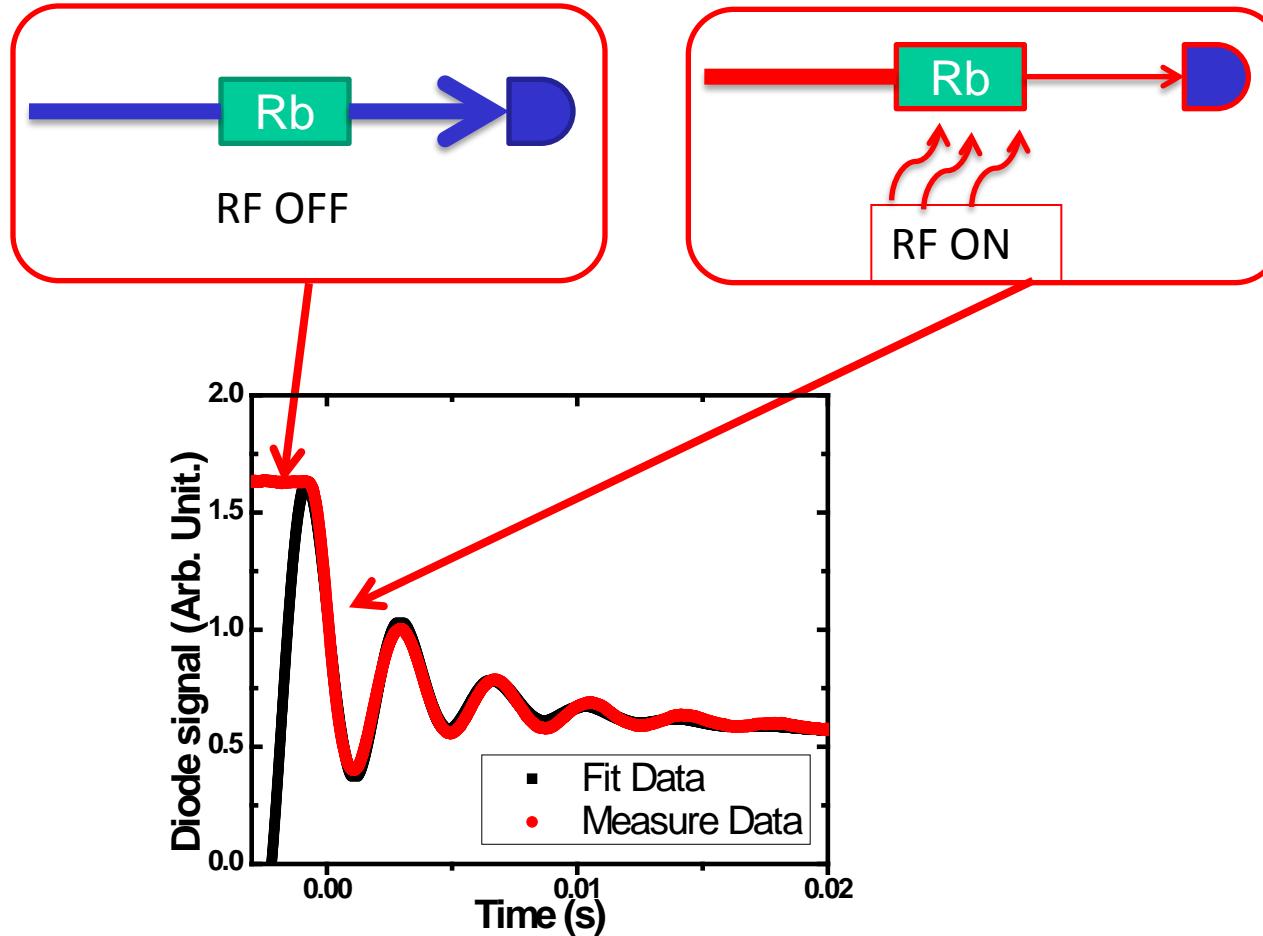
$$g_f = \frac{4 \pi m_e}{e} \times \frac{1}{\text{Slope}}$$

$$g_f \text{ Rb85} = 0.338785 \pm 0.0219$$

$$g_f \text{ Rb87} = 0.510515 \pm 0.0314$$

$$\frac{g_f \text{ Rb87}}{g_f \text{ Rb85}} = 1.5069$$

# Extracting Rabi oscillation frequency

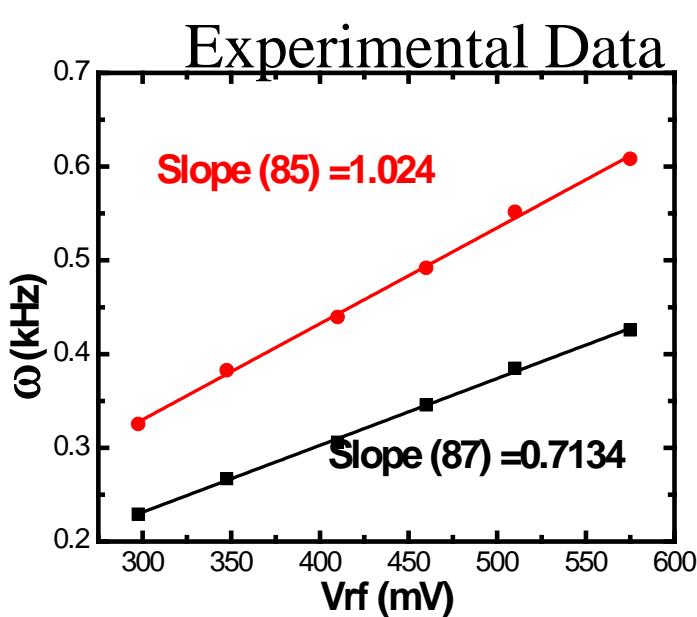


Rabi signal for Rb85 at 347.5V 80kHz RF.

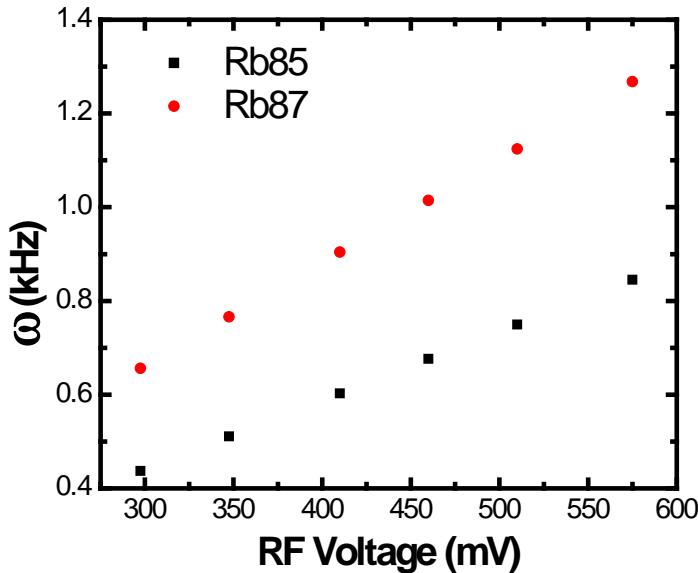
Data is fitted as :  $A + B e^{-t/\tau_1} + C e^{-t/\tau_2} \sin(\omega t + \varphi)$

Only frequency is extracted from the fitted equation.

# Comparing experimental and theoretical data



$$\omega = \gamma l$$



$$\frac{\gamma_{85} * \text{Const}}{\nu_{--} * \text{Const}} \approx 1.4$$

$$\nu = \frac{g_f \mu_0 B}{h} = \frac{g_f e B}{4\pi m_e}$$

Using on-axis magnetic field of a current loop,  $B = \frac{\mu_0 N I R^2}{2(R^2 + X^2)^{3/2}}$  for each coil where R=3.225cm, X=5.4cm, N=3turns, I=current measured.

Theoretical frequency is 2 times higher than measured data. That is due to that RF field is linearly polarized and perturbation is calculated as circular polarization.