# Femto-Tesla magnetometry with FID signals in Cs vapor

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Experimental setup

Experimental results



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Experimental setup

Experimental results



The magnetic moment  $\vec{\mu}$  associated with the spin polarization  $\vec{S}$  precesses at the Larmor frequency

$$\omega_L = \gamma_F |\vec{B}|$$
 where  $\frac{\gamma_F}{2\pi} \approx 3.5 \frac{Hz}{nT}$ 

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# FID = Free Induction Decay

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FID = Free Induction Decay = Free Polarization Decay

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We use an amplitude modulated waveform with  $\omega_{mod} = \omega_L$ .





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Optical pumping			
6 <sup>2</sup> P <sub>1/2</sub>		F = 4	
		F = 3	
<u>6 <sup>2</sup>S<sub>1/2</sub></u>		F = 4	
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Basic idea	Experimental setup	Experimental results	And now?
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Optical pumping			

6 <sup>2</sup>P<sub>1/2</sub>

 $\mathsf{F}=\mathsf{3}$ 

 $6 \, {}^2S_{1/2}$  \_\_\_\_\_ F = 4

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Basic idea	Experimental setup ○○○○○●○	Experimental results	And now? °
Optical pumping			

6 <sup>2</sup>P<sub>1/2</sub>



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Basic idea	Experimental setup	Experimental results	And now? °
Optical pumping			

6 <sup>2</sup>P<sub>1/2</sub>



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Basic idea	Experimental setup		Experimental results •••••••	And now? ○
Basic idea				
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 $\vec{\mu}\propto\vec{\mathsf{S}}\propto\langle\vec{\mathsf{F}}\rangle$ 

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We can make a connection with the population distribution by using

$$\mu_z \propto \langle \mathsf{F}_z \rangle \propto \sum_{m=-4}^4 m \ \mathsf{p}_m \ .$$

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We can make a connection with the population distribution by using

$$\mu_z \propto \langle \mathsf{F}_z \rangle \propto \sum_{m=-4}^4 m \ \mathsf{p}_m \ .$$

The absorption coefficient can be written as

$$\kappa(t) = \kappa_0(1 - ec{\mu} \cdot \hat{k}) = \kappa_0[1 - S_z(t)] = \kappa_0(1 - |ec{S}|\cos\omega_L t) \; .$$

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Experimental setup

Experimental results

And now?

A free induction decay signal

By manually introducing a damping we get

$$\kappa(t) = \kappa_0 (1 - \underbrace{e^{-\gamma t} |ec{S}| \cos \omega_L t)}_{ ext{FID signal}} \; .$$

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Experimental setup

Experimental results

And now?

A free induction decay signal

By manually introducing a damping we get

$$\kappa(t) = \kappa_0 (1 - \underbrace{e^{-\gamma t} |\vec{S}| \cos \omega_L t}_{ ext{FID signal}})$$
 .



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Basic idea Experimental setup Experimental results And now? 0000000 A free induction decay signal By manually introducing a damping we get  $\kappa(t) = \kappa_0 (1 - \underbrace{e^{-\gamma t} |\vec{S}| \cos \omega_L t})$ . FID signal Raw FID data S ) 1.05 1.00 1.00 0.95 w 0.90 0.95 0.00 0.01 0.02 0.03 0.04 0.05 0.06

time (s)



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fT magnetometry with free induction decay signals





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The fit of the FID yields

$$B = 1.0152622(2) \ \mu T$$
.

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Experimental setup

Experimental results

And now?

Sensitivity characterisation

The magnetometric sensitivity of a single FID on the measurement time  $T_{probe}$  scales as

$$\delta B_{1FID} \propto rac{1}{SNR \ T_{probe}^{3/2}} \ .$$

Experimental setup

Experimental results

And now?

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The sensitivity using N consecutive FID cycles is given by

$$\delta B_N = rac{\delta B_{1FID}}{\sqrt{N}} \; .$$

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Experimental setup

Experimental results

And now?

Sensitivity characterisation

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We typically get values of

 $\delta B_{1FID} = 1.5 \ pT$  and  $\delta B_{N=5} = 300 \ fT$ .

In shot noise limit we may achieve  $\delta B_{N=5} = 60 \ fT$ .

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## Experimental setup

## Experimental results

### For 30% duty cycle



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## Experimental setup

## Experimental results

### For 30% duty cycle



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Basic idea	Experimental setup	Experimental results	And now?
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For 30% duty cycle	е		

The highest sensitivity can be reached for a pump amplitude of  $\approx 20 \mu A$ .



Basic idea	Experimental setup	Experimental results	And now?
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For 30% duty cycle	9		

The highest sensitivity can be reached for a pump amplitude of  $\approx 20 \mu A.$ 



The highest sensitivity in shot noise limit we get is  $\delta B = 60 \frac{fT}{\sqrt{Hz}}$ .



Probe

'3 μW

fT magnetometry with free induction decay signals

65 µW

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Pump

The duty cycle of the pump waveform has to be 30%.

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Investigation o	f systematic effects		



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Investigation c	f systematic effects		



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