

Optimized detection modality for double resonance alignment based optical magnetometer

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Introduction

- RF magnetometers offers high sensitivity ($\text{fT}/\sqrt{\text{Hz}}$) to the oscillating magnetic fields. The ability of rf magnetometers to detect fields in kHz--MHz frequency band promises their applications in diverse fields [1-- 4].
- Commercial magnetometers rely on measuring the absorption of light transmitted through the atomic vapor cell.
- Theoretical model [5] and experimental demonstration for another detection modality are presented.
- The results demonstrate and reveal that the polarization rotation detection mode yields larger signals and better sensitivity than absorption measurement of light.

Experimental Setup

- Illustration of the DRAM geometry where linearly polarized light interacts with Caesium (Cs) atomic vapours in the presence of a static and oscillating magnetic field. (b) Caesium level scheme.
- Light ($10 \mu\text{W}$) with a wavelength of 894.6 nm , resonant with the $F=4 \rightarrow F=3$ Cs D1 transition, is used to pump and probe the Cs atoms.
- Balanced photodetection scheme detects the rotation of plane of polarization of light transmitted through the cell. For absorption measurement, we replace the BPD scheme with a single photodetector.
- The Cs atoms are in a paraffin-coated cell (20°C , $(5\text{mm})^3$).

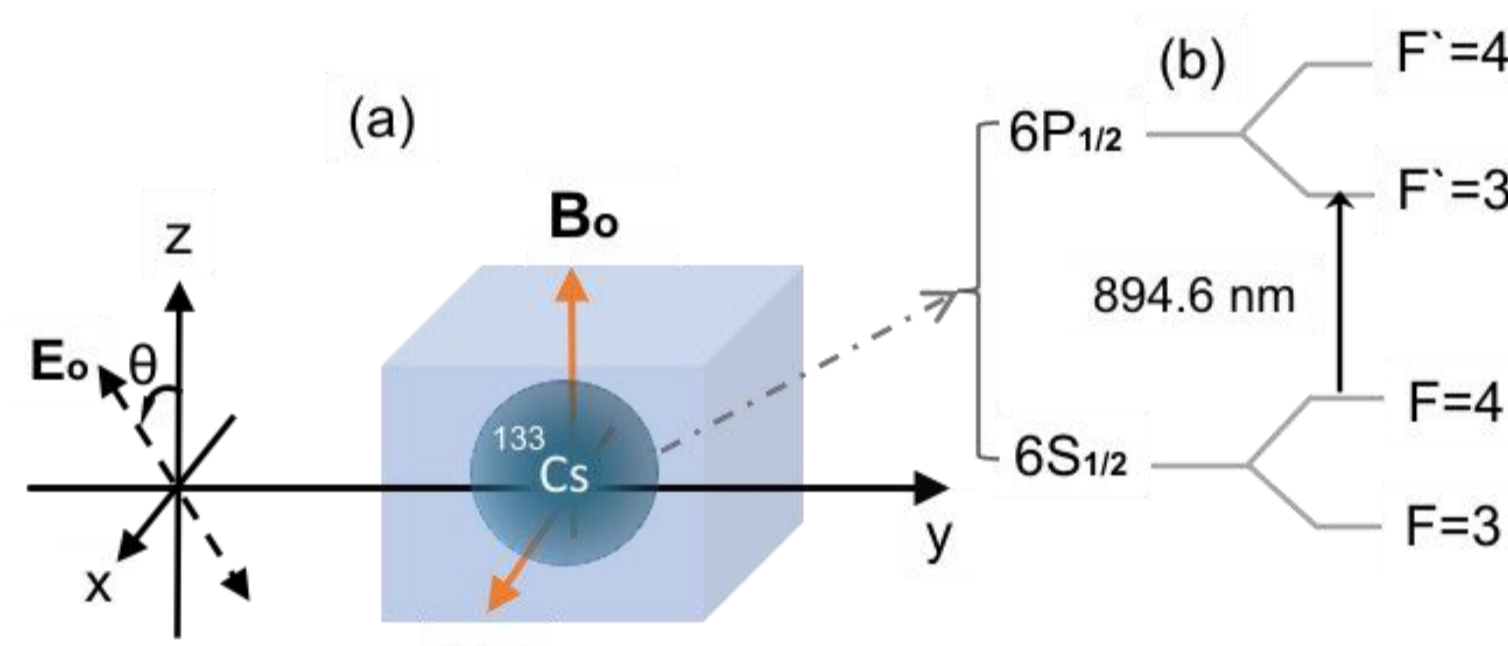


Figure 1: Illustration of DRAM geometry.

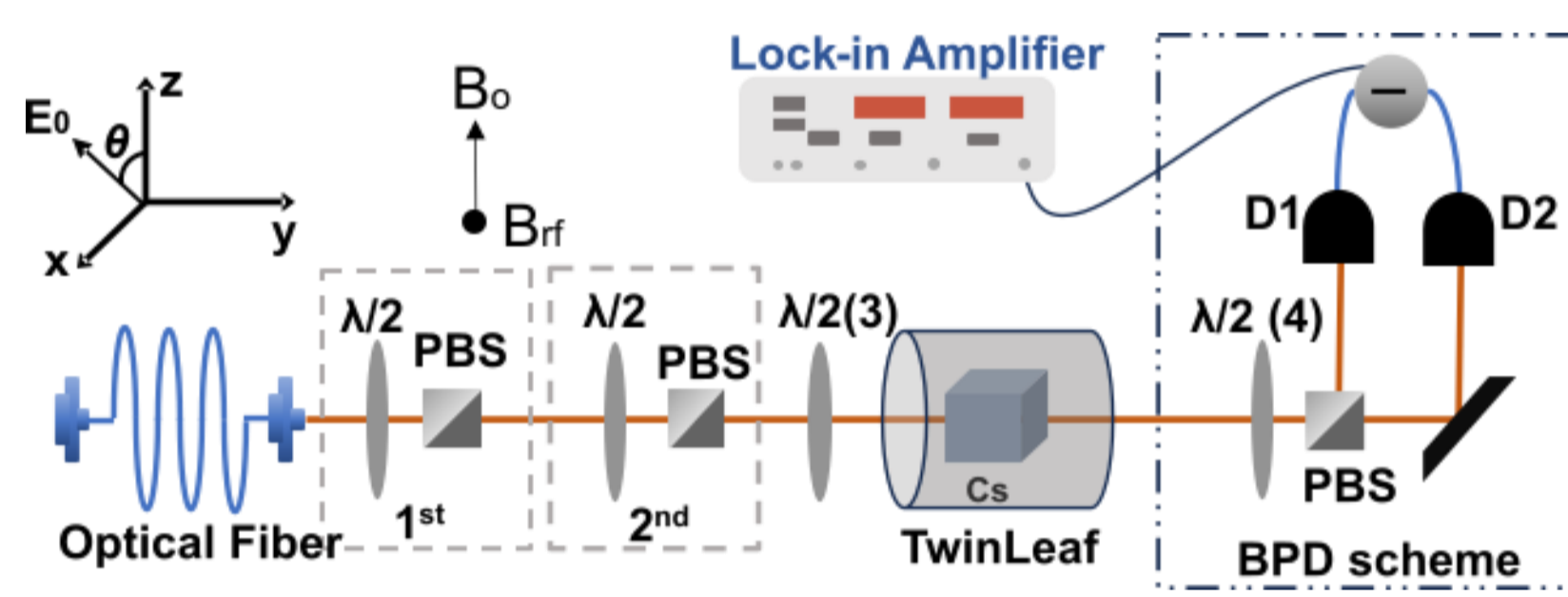


Figure 2: Schematic of the experimental setup.

Theory

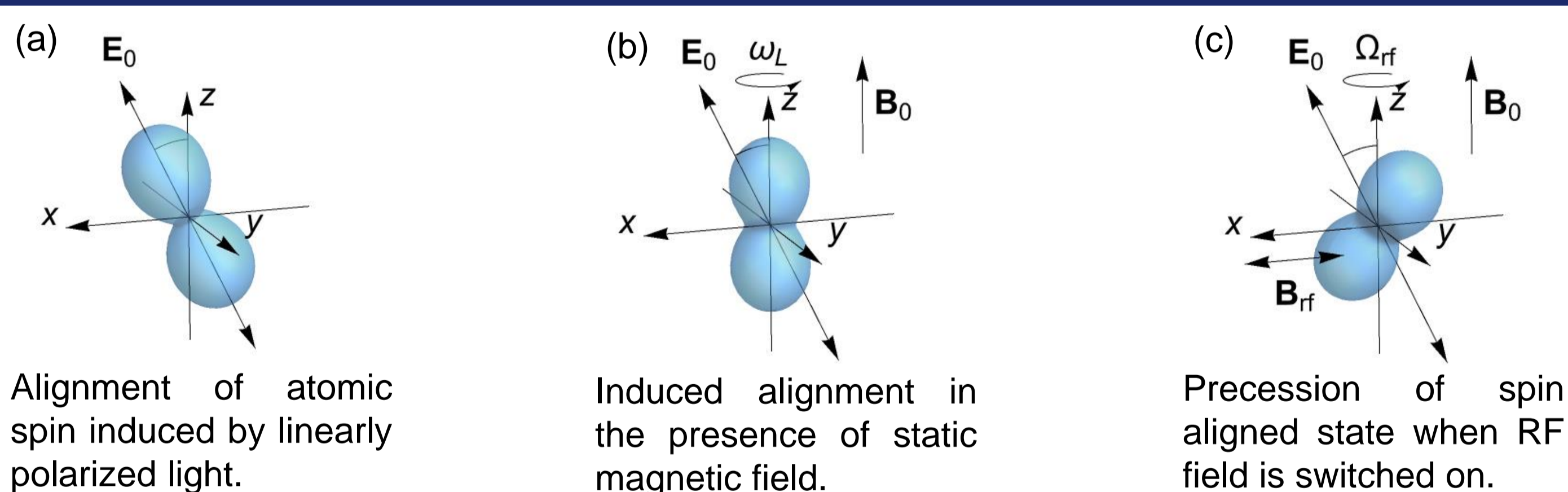


Figure 3: Evolution of aligned atomic spins.

- The polarization rotation signal will oscillate at the first and second harmonic of oscillating RF-field and is given by

$$S_1^{pr}(t) \propto h_1(\theta) [D_1 \cos(\omega_{rf} t) + A_1 \sin(\omega_{rf} t)]$$

$$S_2^{pr}(t) \propto h_2(\theta) [A_2 \cos(\omega_{rf} t) + D_2 \sin(2\omega_{rf} t)]$$

Where angular dependence has the following form

$$h_1(\theta) = \cos(2\theta) [1 + 3\cos(2\theta)]$$

$$h_2(\theta) = \sin(2\theta) [1 + 3\cos(2\theta)]$$

and in-phase and quadrature signals for 1st harmonic are given by

$$A_1(\delta, \Omega_{rf}) = \sqrt{\frac{3}{2}} \frac{m_{2,0}^{ini} (2(R^2 + 4\delta^2) + \Omega_{rf}^2)}{4(R^2 + 4\delta^2 + \Omega_{rf}^2)(4(R^2 + \delta^2) + \Omega_{rf}^2)}$$

$$D_1(\delta, \Omega_{rf}) = \sqrt{\frac{3}{2}} \frac{m_{2,0}^{ini} \delta \Omega_{rf} (2(R^2 + 4\delta^2) - \Omega_{rf}^2)}{2(R^2 + 4\delta^2 + \Omega_{rf}^2)(4(R^2 + \delta^2) + \Omega_{rf}^2)}$$

Where $R_1 = \sqrt{A_1^2 + D_1^2}$

$$R_1(\delta=0, \Omega_{rf}) = \sqrt{\frac{3}{2}} \frac{m_{2,0}^{ini} \Gamma \Omega_{rf}}{4(R^2 + \Omega_{rf}^2)}$$

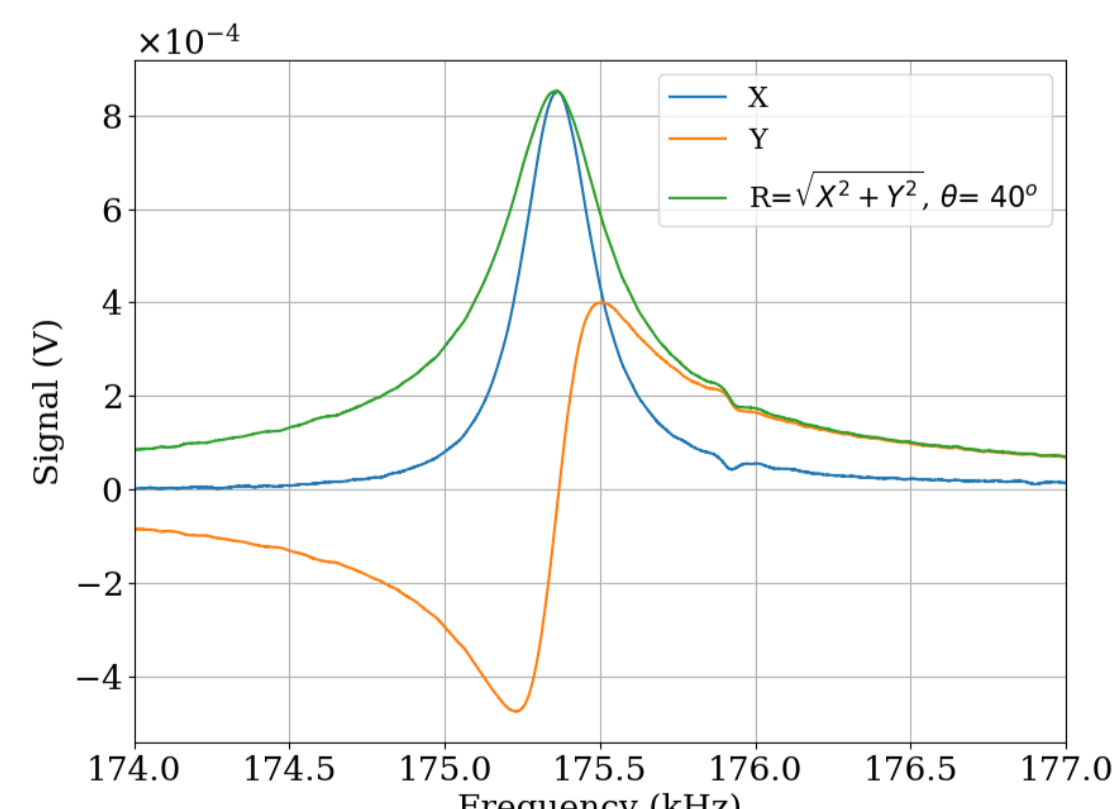


Figure 4: First harmonic signals (in-phase and quadrature) of magnetic resonance spectra at resonance. The data is taken in the earth's magnetic field range.

Angular Dependence of Resonance Spectra

- Signal from BPD/ single photodetector is registered while input light polarization is varied.
- Magnetic resonance signal from BPD is demodulated by lock-in amplifier.
- Data is analyzed and amplitude of resonance spectra is plotted against the input polarization angle and curve fitted to the equations for respective harmonics.
- Experimental results agree well with the theoretical findings at low light power.

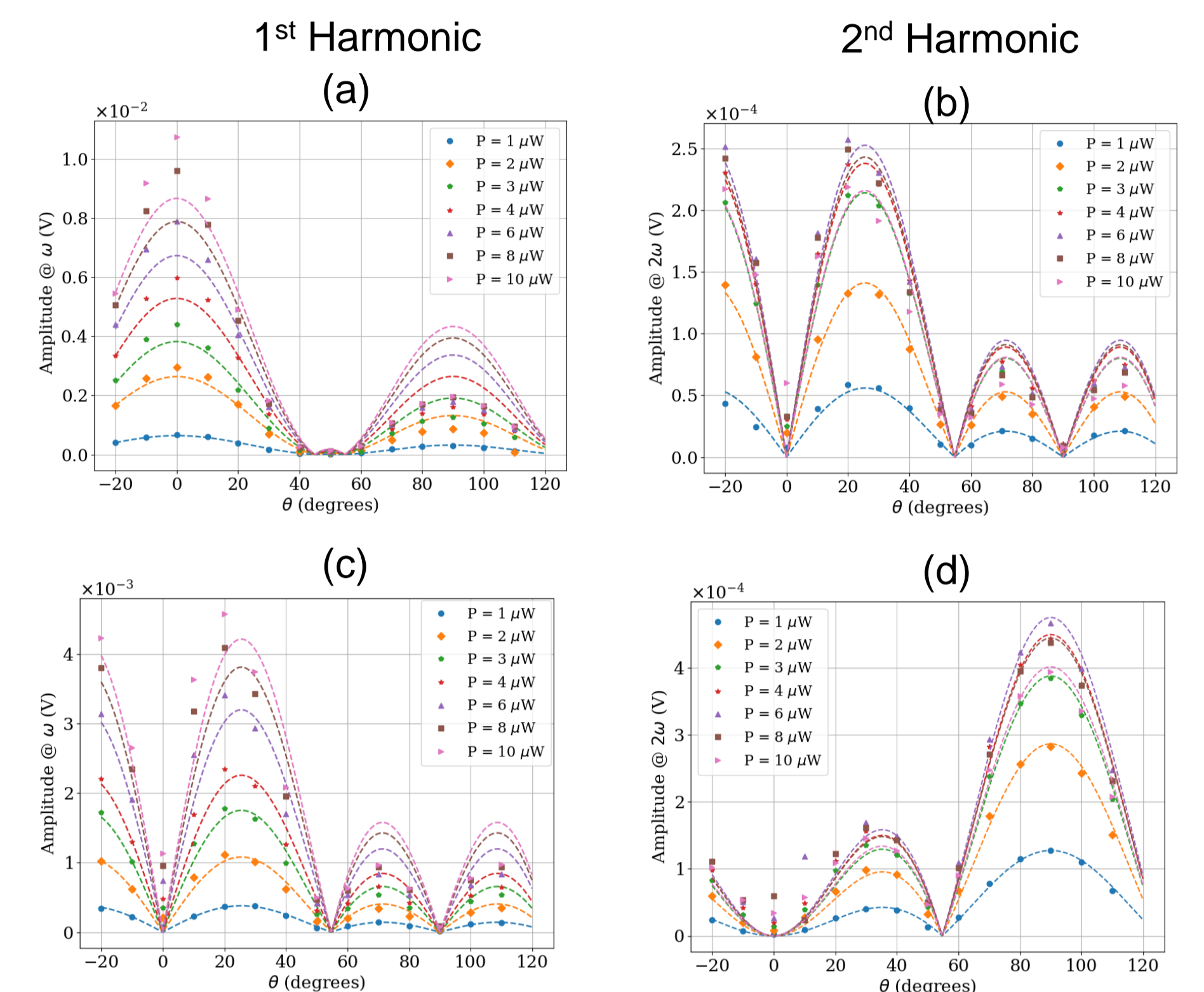


Figure 5: The amplitude of magnetic resonance signal as the polarization angle of input light is varied.

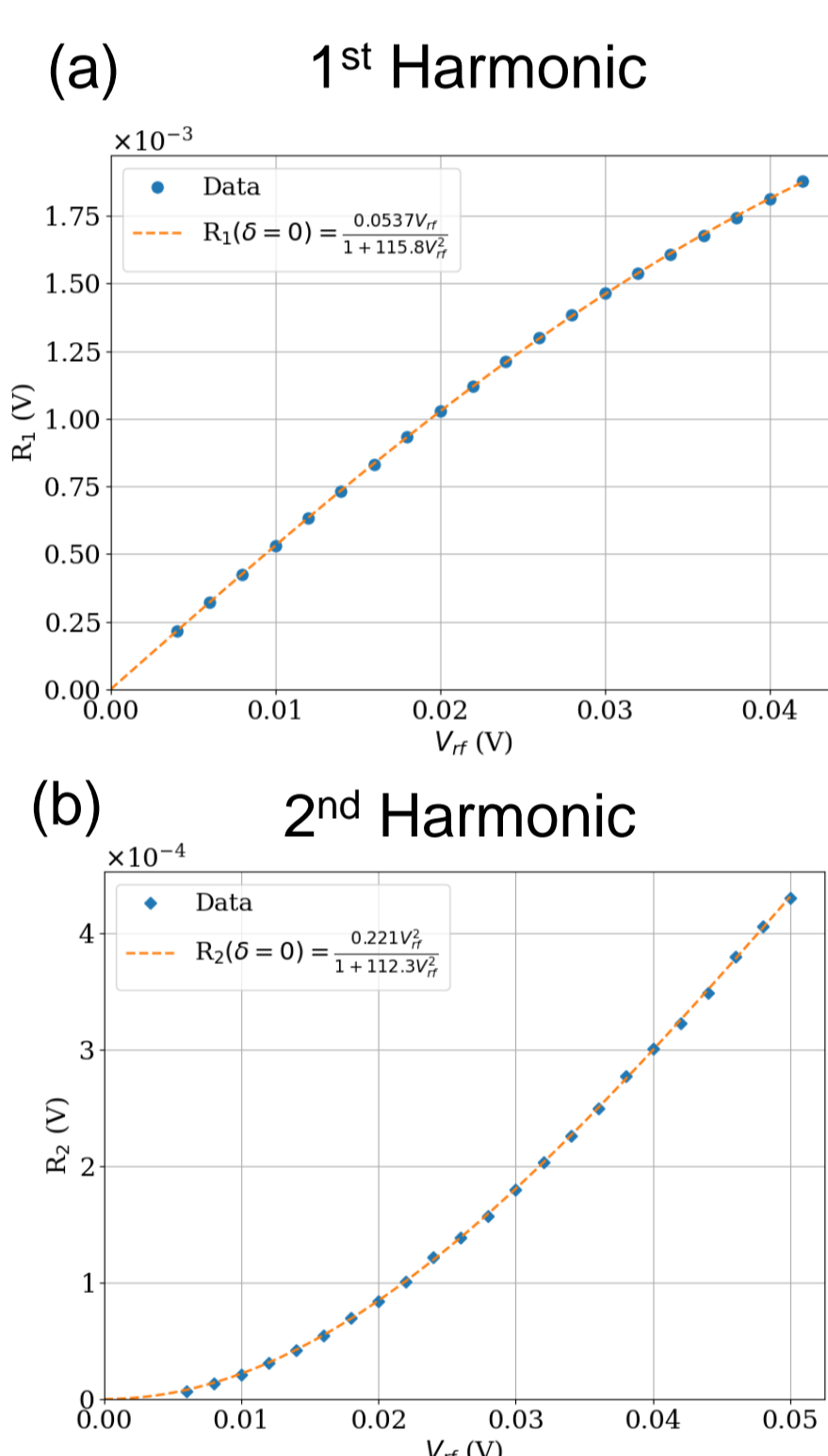


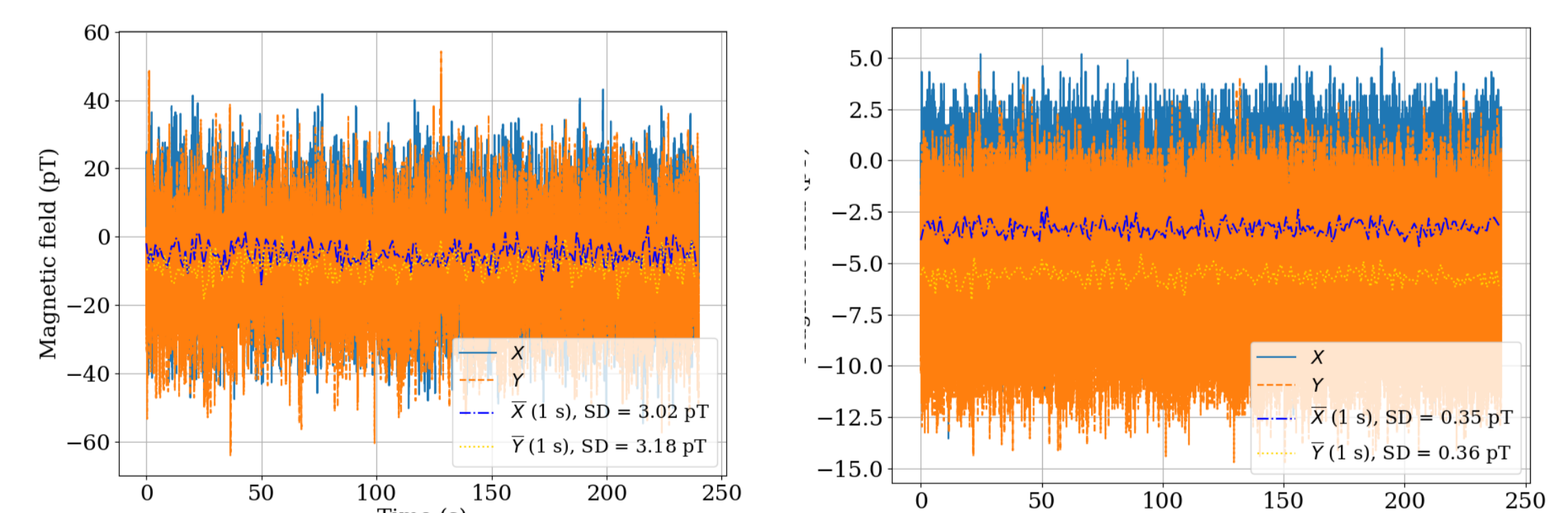
Figure 6: The amplitude of magnetic resonance signal as the RF-magnetic field amplitude is varied for 1st and 2nd harmonic. The results presented are obtained through BPD scheme.

Sensitivity Measurements

- A static field sets the Larmor frequency 9.5 kHz . RF-field frequency is fixed to the Larmor frequency and 4 minute time trace is obtained.
- The data is analyzed to estimate the sensitivity by taking the standard deviation of $240 \times 1\text{s}$ averaged segments [3].

	$pT/\sqrt{\text{Hz}}$	δB_{mea}	δB_{elec}	δB_{shot}	δB_{proj}
Absorption	3.0	1.34	0.80	0.042	
Polarization	0.35	0.25	0.26	0.046	

Figure 7: Sensitivity measurement done through (a) polarization rotation and (b) absorption measurement.



Conclusions

- Polarization rotation offers better sensitivity, approximately an order of magnitude in our case, than absorption measurement. Moreover, if experimental setting is limited by shot noise, the sensitivity through polarization rotation is better by a factor of 3.
- RF-alignment magnetometers require low power hence they are also compatible with low power vertical cavity surface emitting lasers (VCSEL). Leveraging the use of single laser and compatibility with VCSEL made them an ideal candidate for miniaturization and advancing the commercialization of compact, robust RF-alignment OPMs. The detail analysis of optimization parameters for such RF-alignment magnetometer is advantageous in this respect