Nuclear Magnetic Resonance Gyroscopes for Precise Positioning

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Abstract:

Precise positioning of vehicles is essential for modern mobility solutions. In the case when GPS signals and other systems are temporarily unavailable, high performance inertial sensors become a key component of navigation systems that widely use dead reckoning i.e. localization based on a previously determined position and precise directional sensor signals, including rotation and acceleration.

Nuclear Magnetic Resonance (NMR) based gyroscopes enable high precision measurement of rotation rates – with a high potential of miniaturization. We present modelling of a Xenon and Rubidium based NMR gyroscope for parameter studies.

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ZULF NMR

NMR Gyroscopes: Working Principle

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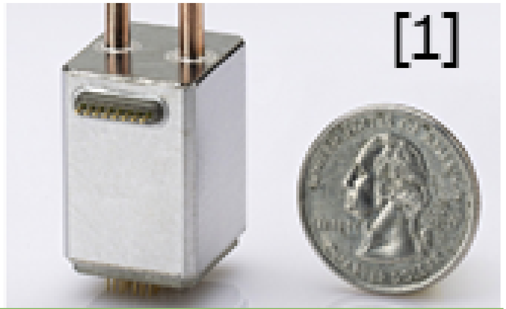
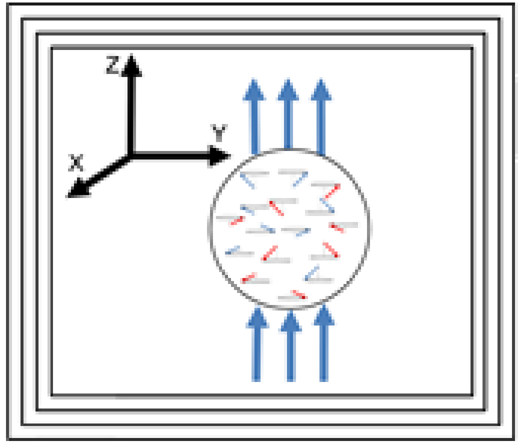
Working Principle Scheme:

Rubidium (↗) and Xenon (↗) magnetic moments.
Static (→) and oscillating (↔) magnetic fields.
Lasers (🟥) with positive propagation direction.
Linear and circular polarization (↔).
Global magnetization of the cell is illustrated in the coordinate representation.

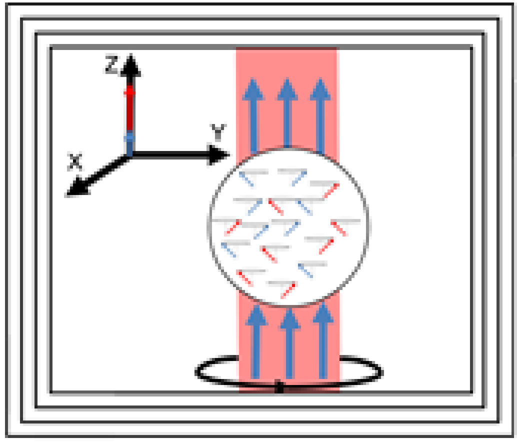
Previous work [1] measuring a shift in the measured frequency of Xenon Larmor-precession due to rotation, with an in-situ Rubidium magnetometer has shown an angular random walk of 0.005°/$\sqrt{\text{h}}$ and a bias drift of 0.02°/ h.



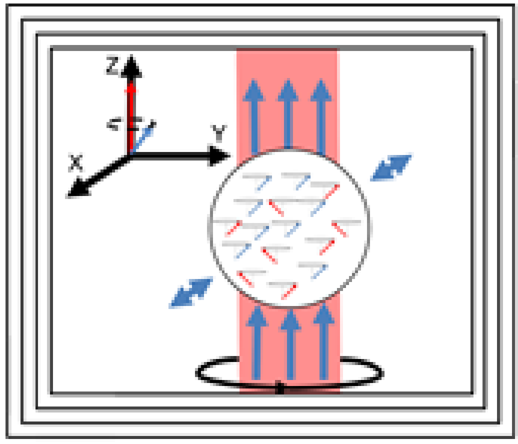
Larmor-Precession



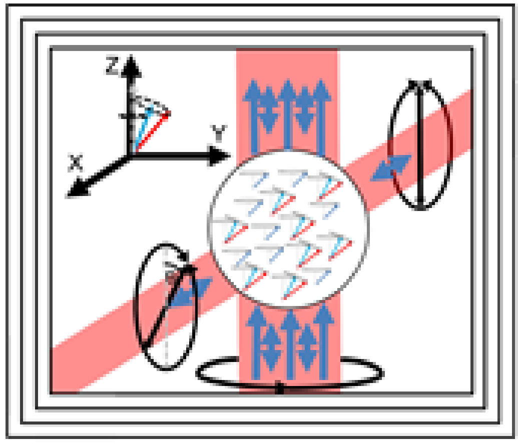
Spin Exchange Optical Pumping



Resonant Driving



Parametric Modulation and Optical Rotation Detection



[1] T.G. Walker and M.S. Larsen: Spin-Exchange Pumped NMR Gyros, Adv. Atom. Mol. Opt. Phys. 65, 373-401 (2016)

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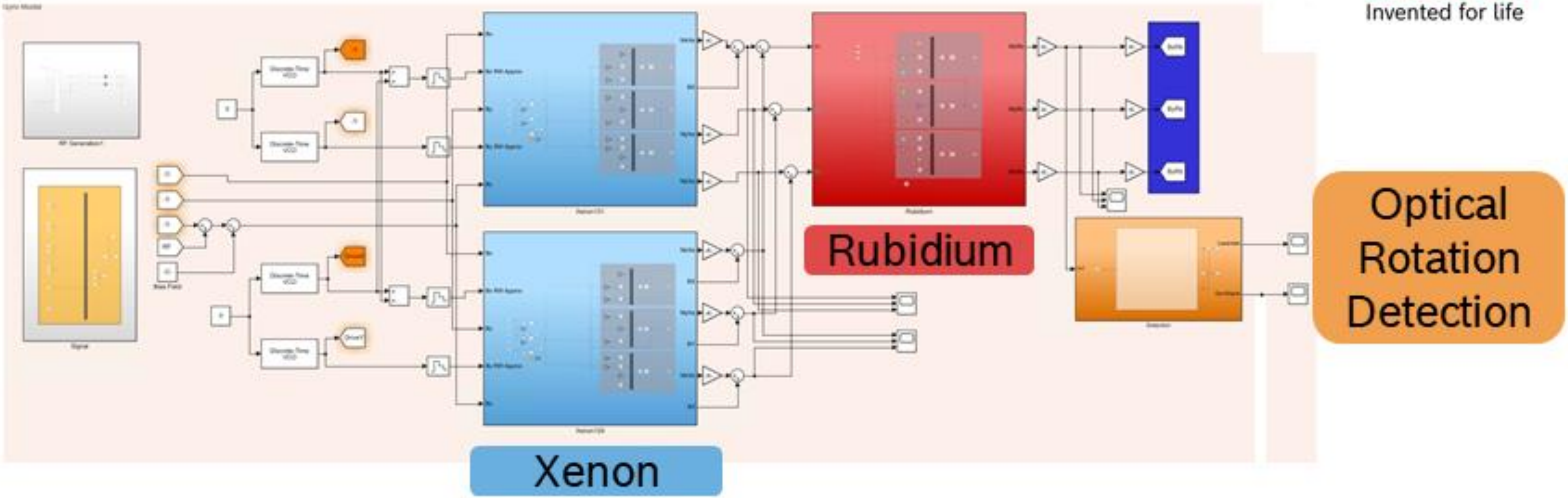
Modelling with MATLAB and Simulink



- Numerical solution of the Optical Bloch equations for arbitrary fields
- No steady state approximation
- Feedback of the alkali field.
- Simulation for arbitrary system parameters

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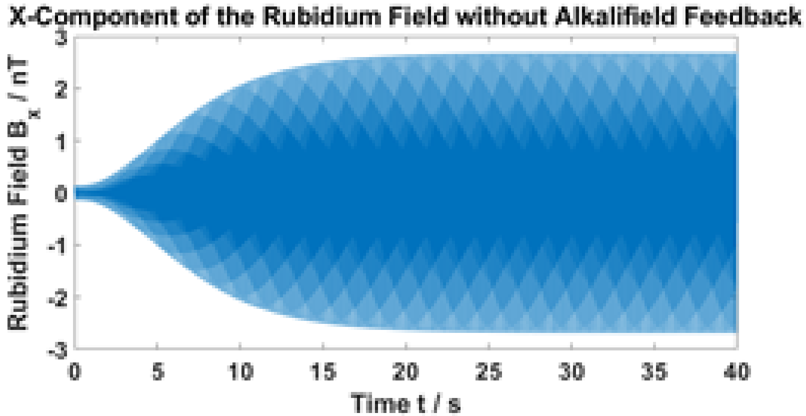
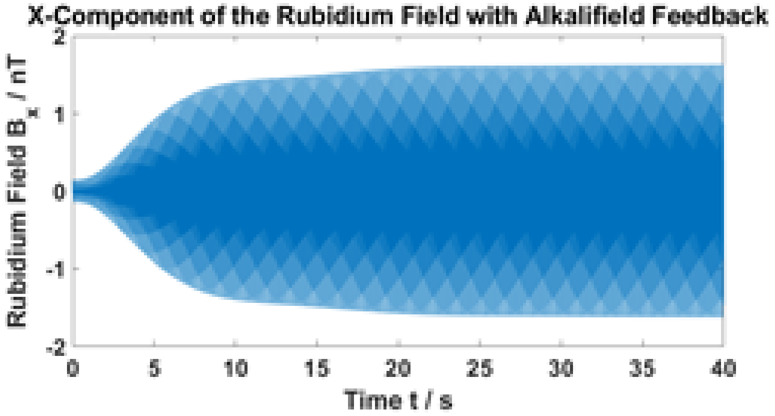
Results and Conclusions

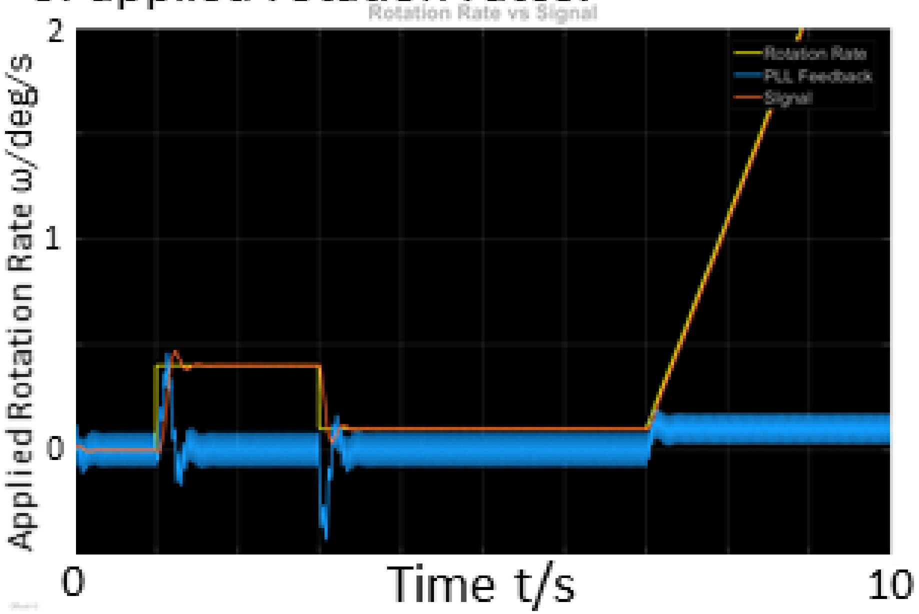
Precession signals that agree with the analytical steady state solution:



Adding interaction terms e.g. due to the alkali field:



Functional reconstruction of applied rotation rates:



The Gyroscope Signal (Red) reconstructs an applied Rotation Rate (yellow). Blue shows the non-integrated feedback of a Phase Locked Loop.

Outlook:

- Parameter studies
- Optimized control and read-out

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