
This version is available at https://strathprints.strath.ac.uk/58932/

Strathprints is designed to allow users to access the research output of the University of Strathclyde. Unless otherwise explicitly stated on the manuscript, Copyright © and Moral Rights for the papers on this site are retained by the individual authors and/or other copyright owners. Please check the manuscript for details of any other licences that may have been applied. You may not engage in further distribution of the material for any profitmaking activities or any commercial gain. You may freely distribute both the url (https://strathprints.strath.ac.uk/) and the content of this paper for research or private study, educational, or not-for-profit purposes without prior permission or charge.

Any correspondence concerning this service should be sent to the Strathprints administrator: strathprints@strath.ac.uk
Magnetometry Optimisation in Unshielded Environments

Stuart Ingleby
Strathclyde University
Glasgow
Introduction

Strathclyde University
Quantum Sensors & Metrology Lab
- Clocks, Magnetometry and Rotation sensors
March 2015
Introduction

- Unshielded Magnetometry
  - Surveying
  - Seismology

- Performance criteria
  - Sensitivity
  - Bandwidth
  - Portable & scalable
  - Arbitrary fields
  - Noise rejection
Introduction

• Unshielded Magnetometry
  • Surveying
  • Seismology

• Performance criteria
  • Sensitivity
  • Bandwidth
  • Portable & scalable
  • Arbitrary fields
  • Noise rejection

• Single-laser NMOR
• Software control & feedback
• Iterative optimisation
Introduction

- Unshielded Magnetometry
  - Surveying
  - Seismology
- Performance criteria
  - Sensitivity
  - Bandwidth
  - Portable & scalable
  - Arbitrary fields
  - Noise rejection

Cs cell
- 28 mm diameter
- 2x10^{-6} torr Cs vapour
- Paraffin anti-relaxation
- 7 Hz intrinsic relaxation
- Made in Fribourg [1]

NMOR resonance

\[ X = A x \left[ \frac{1}{1+x^2} - \frac{S^2}{2} \frac{(7+10x^2)}{(1+x^2)^2(1+4x^2)} \right] \]

\[ Y = A \left[ \frac{1}{1+x^2} - \frac{S^2}{2} \frac{(4+7x^2)}{(1+x^2)^2(1+4x^2)} \right] \]

- \( B_0 // \) polarisation
- First-harmonic response
- \( B_{RF} \) modulation
- Software
  - Demodulation
  - Phase correction
  - Regression


25/05/16 Stuart Ingleby DAMOP 2016
B$_0$ Orientation & Gradient

- B$_0$ orientation
  - B$_0$ // polarisation

- Relaxation $\Gamma \propto |\nabla B|^2$ [3]

**B₀ optimisation**

- **Finite-field optimisation**
  1. Minimise $B_x$
  2. Set $B_y$
  3. Minimise HWHM wrt $\nabla B_x$ $\nabla B_y$ $\nabla B_z$

*25/05/16 Stuart Ingleby DAMOP 2016*
**B₀ optimisation**

- Finite-field optimisation
  1. Minimise $B_x$
  2. Set $B_y$
  3. Minimise HWHM wrt $\nabla B_x$, $\nabla B_y$, $\nabla B_z$

Δ$B_0 < 20$ nT

$\nabla B < 2$ nT/mm
**$B_0$ optimisation**

- Finite-field optimisation
  1. Minimise $B_x$ and $B_y$
  2. Set $B_z$
  3. Minimise HWHM wrt $\nabla B_x$, $\nabla B_y$, $\nabla B_z$

![Graph showing Bz measured error vs Bz applied (µT) with data points and a trend line.](image)
**B₀ optimisation**

- Finite-field optimisation
  1. Minimise Bₓ, Bᵧ
  2. Set Bₓ
  3. Minimise HWHM wrt \( \nabla Bₓ, \nabla Bᵧ, \nabla Bₓ \)
$B_0$ optimisation

- Finite-field optimisation
  1. Minimise $B_x$ and $B_y$
  2. Set $B_z$
  3. Minimise HWHM wrt $\nabla B_x$, $\nabla B_y$, $\nabla B_z$

Convergence 2-3 iterations

$\Delta B_0 < 20 \text{ nT}$

$\nabla B < 2 \text{ nT/mm}$
B₀ optimisation

- Finite-field optimisation
  1. Minimise Bₓ, Bᵧ
  2. Set Bẑ
  3. Minimise HWHM wrt ∇Bₓ, ∇Bᵧ, ∇Bẑ

Convergence 2-3 iterations

ΔB₀ < 20 nT
∇B < 2 nT/mm

25/05/16

Stuart Ingleby DAMOP 2016
B_0 optimisation

- Finite-field optimisation
  1. Minimise B_x, B_y
  2. Set B_z
  3. Minimise HWHM wrt ∇B_x, ∇B_y, ∇B_z

- Convergence 2-3 iterations
  - ΔB_0 < 20 nT
  - ∇B < 10 nT/mm
$B_{RF}$ optimisation

- Signal
  \[ A \propto B_{RF} \]
- Saturation
  \[ S = \frac{B_{RF}g_F}{\Gamma} \approx 1 \]
Optimised resonance

- HWHM 680 → 108 Hz (7 Hz intrinsic)
- Sensitivity 228 → 20 pT.Hz$^{-1/2}$
Stability & Dynamic range

- Dipole ~ 8 mA.m²
- Location < 5 mm
Response & Noise measurement

- Software PID feedback
  - Self-optimised
    - Phase
    - Gain
- 1 Hz field tracking
Summary

• QT Hub: application of QT to devices
• Unshielded vapour cell magnetometry
  • Scalable, flexible ➔ Hardware < Software
  • Arbitrary fields ➔ Studying $B_0$ & $\nabla B$
  • Sensitivity ➔ Noise rejection