Science and Technology Facilities Council

RAL Space

Magnetic Shields for Quantum Sensors in Space

Final Review Meeting 24/03/2023

Agenda

1. Overview
Work packages

2. Study of optimisation
Passive shielding
Material choice and degaussing
Geometry
Active cancelation

3. Magnetic shield prototype
Manufacture
Characterisation
Conclusion

4. Project management
Documentation required

Science and Technology Facilities Council
RAL Space

Overview

This activity was divided in two main work packages:

- Study of optimisation work package looked at the current limitations, simulating the already existing magnetic shield system and exploring ways of improving this system.

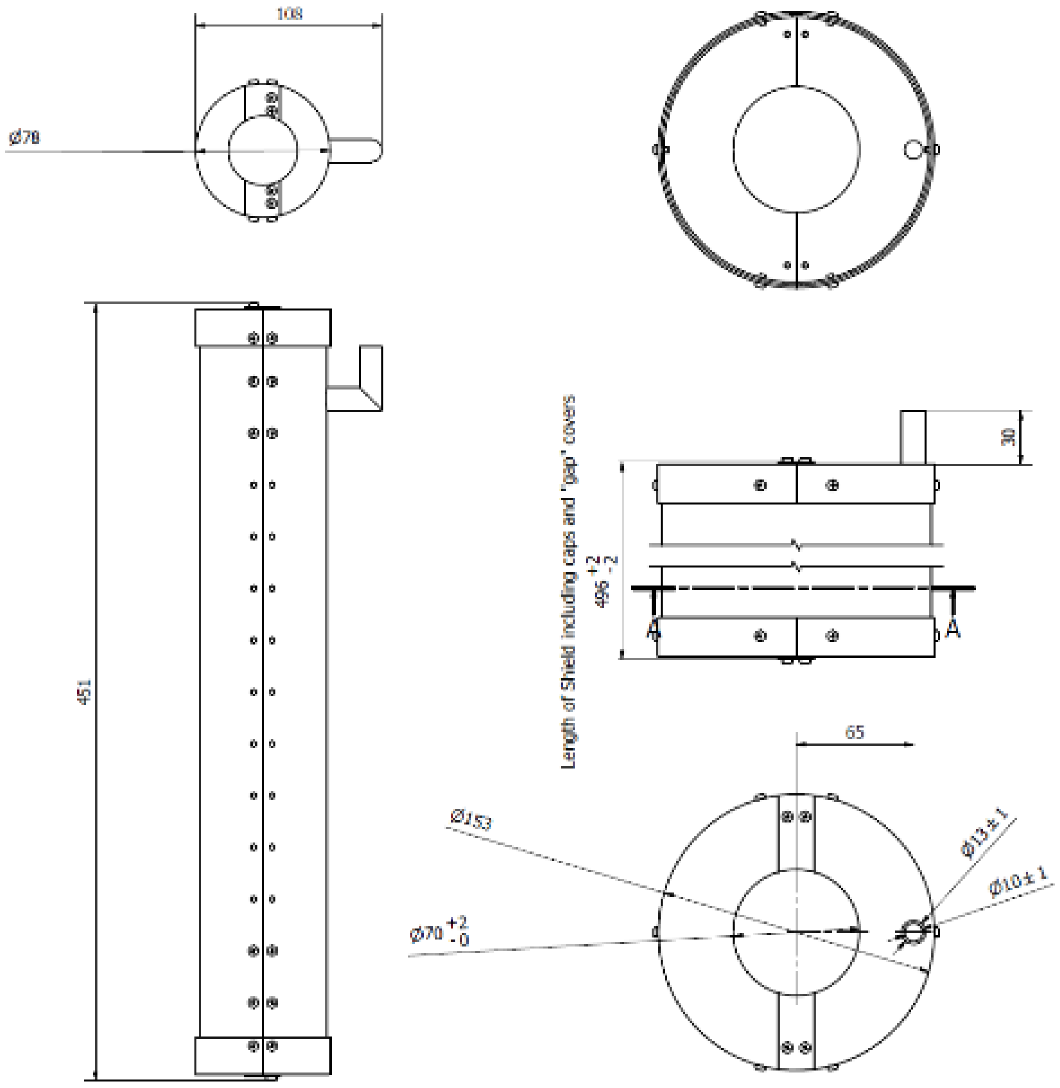
- Magnetic shield prototype work package exploited the outcomes of the previous work package and converted it into a new magnetic shielding design ready for manufacture. At the end of this, both systems were experimentally characterised and the SWaP improvements quantified.

Science and Technology Facilities Council

RAL Space

Passive shielding

- Current magnetic shielding system at RAL Space is composed of a two-layer shield of mu-metal material of 1.5 mm in thickness, optimised for the CAI-based gravity gradiometer.
- The inner layer is 1.824 kg and the outer layer 3.626 kg, for a total combined mass of 5.45 kg

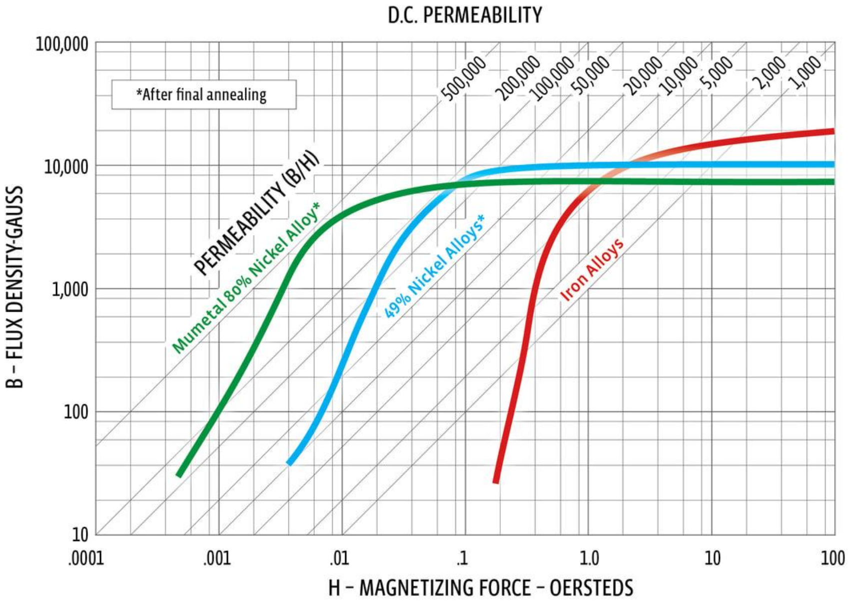


Science and Technology Facilities Council

RAL Space

Material choice

- Magnetic permeability
- Saturation intensity

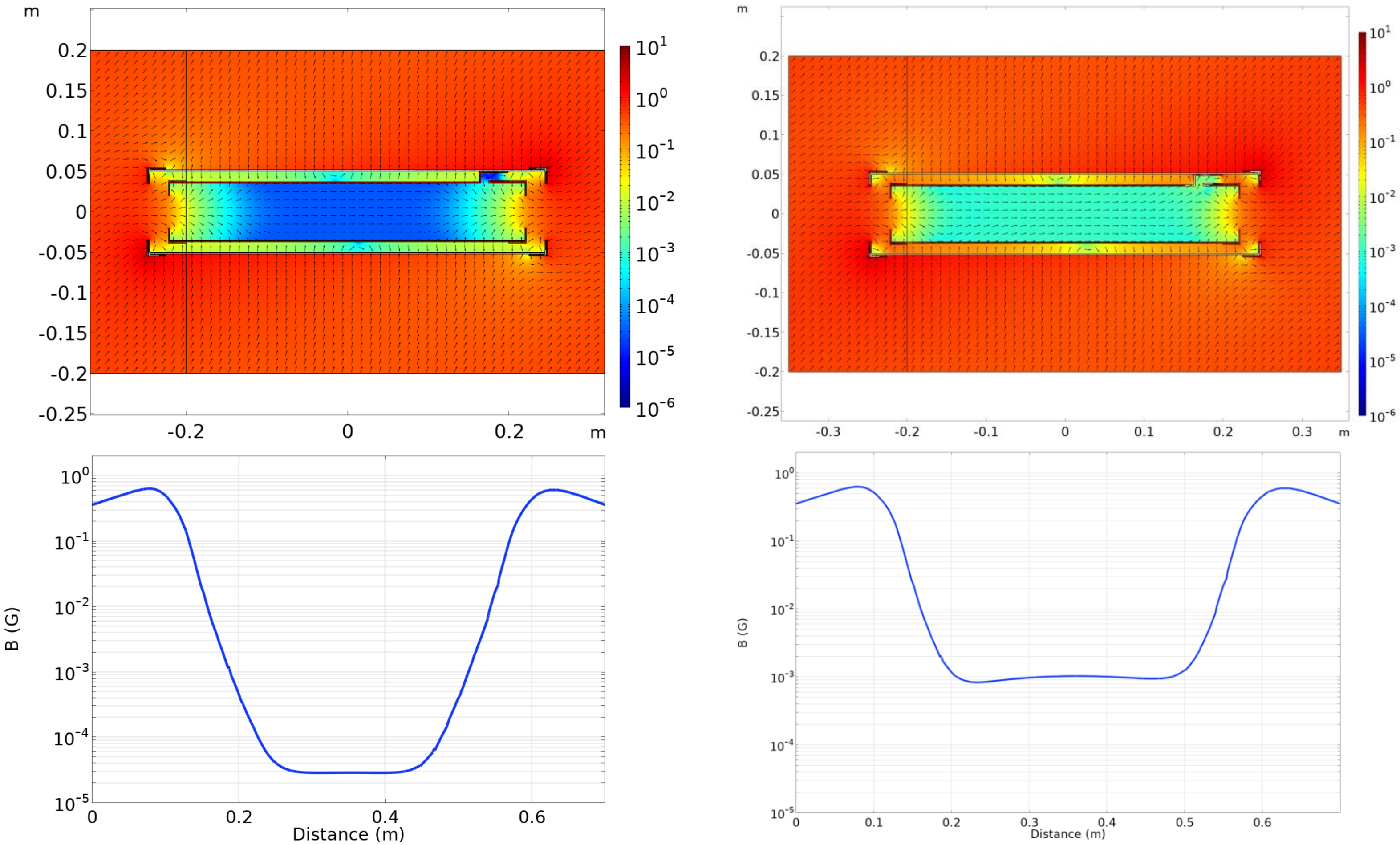


Raw material	Density (g/cm^3)	Permeability μ
Neodymium magnet		1.05
Nickel	8.902	100 – 600
Iron	7.874	500 – 10,000
Iron annealed in H		200,000
Molybdenum	10.22	
Copper	8.93	0.999994

Alloy	Composition	Saturation (G)	Permeability μ
Permalloy	78% nickel 19% iron 3% molybdenum		10^4 – 10^5
Mumetal	77% nickel 16% iron 5% copper 2% molybdenum	~7,500	10^5
Supermalloy	75% nickel 20% iron 5% molybdenum		10^5 – 10^6
Supra50	48% nickel 52% iron	~10,000	

Material choice

- Iron has higher saturation so preferred to shield larger fields, however, has lower permeability than mu-metal
- Annealing in hydrogen atmosphere needed to increase permeability
- Degaussing needed to demagnetize materials



Simulations of a two-layer magnetic shield system with a higher permeability value on the left (mu-metal) than on the right (iron).

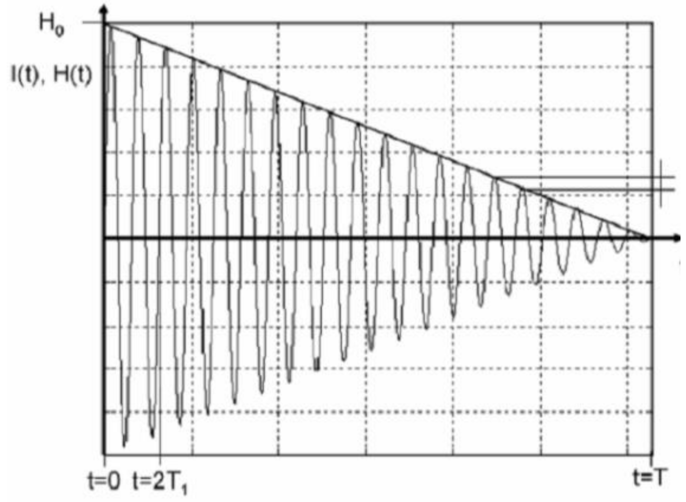
Science and Technology Facilities Council

RAL Space

Degaussing

- Principle:
  - Closed magnetic "circuit"
  - Oscillating signal brings material into saturation
  - Amplitude decreases slowly

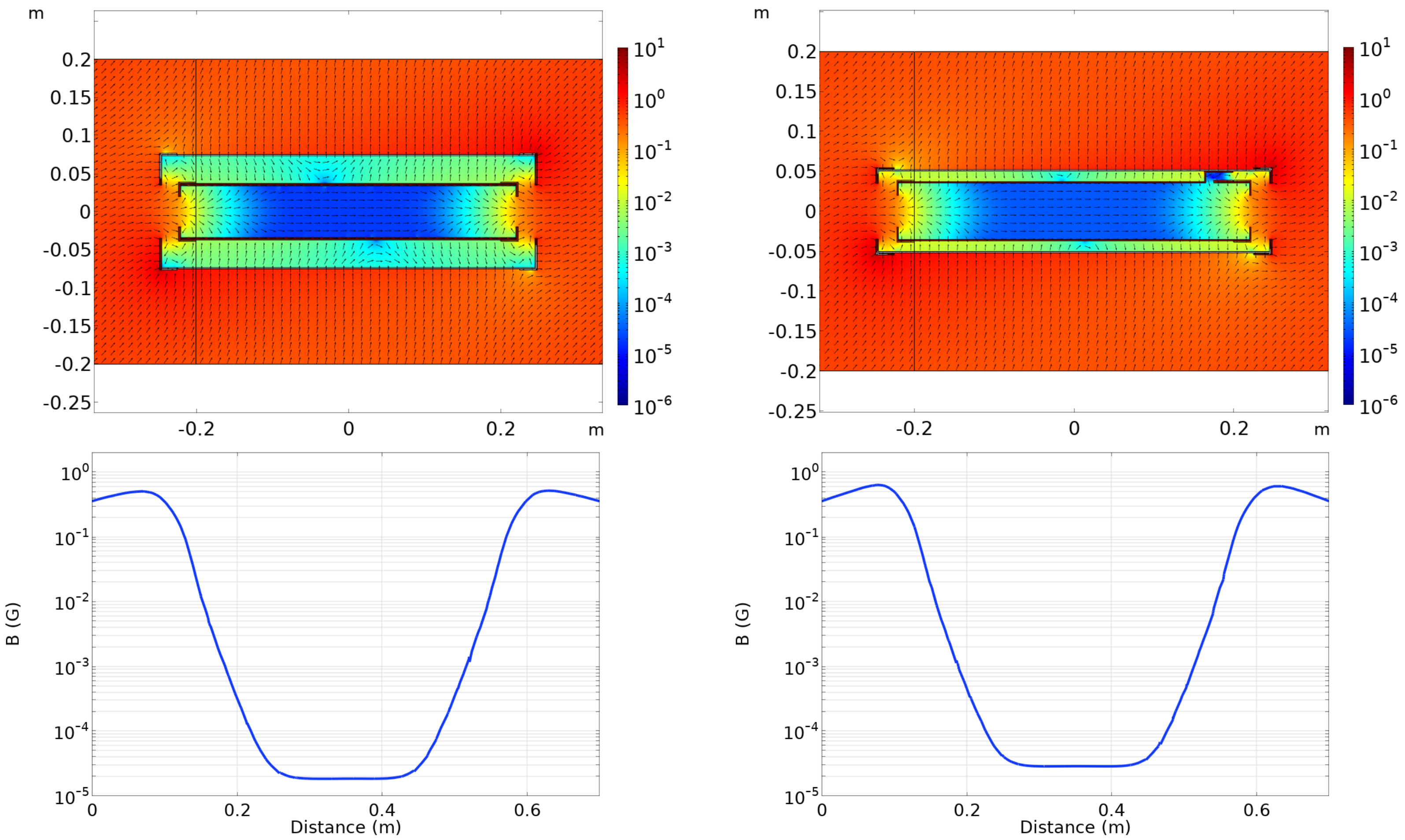
- Electronic requirements:
  - Each equilibration sequence starts with an amplitude that saturates the magnetizable material and then linearly decreases over 1000 cycles to below noise level → **high power consumption**
  - **Expensive** digital to analogue converter
  - **Heavy transformer** to remove DC offset



Geometry

- Larger spacing between layers increases shielding performance, however, this is not linear, so a compromise should be found

- Gaps and holes are more important than geometrical details

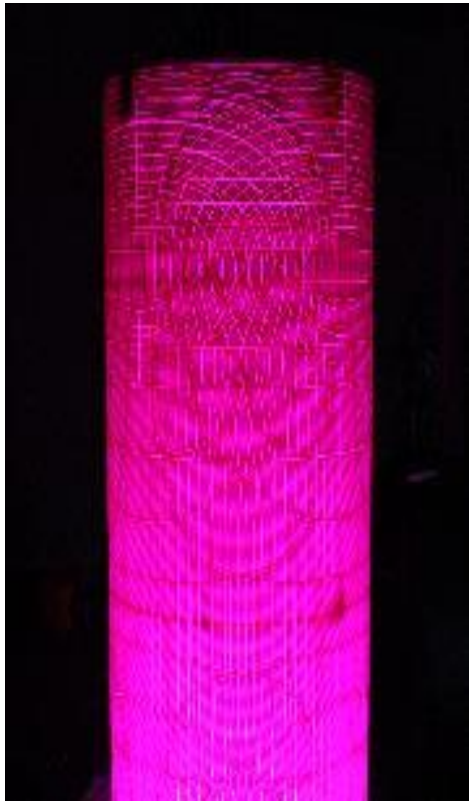


Simulation of the magnetic shielding system with same materials, only changing the gap between layers.

Science and Technology Facilities Council
RAL Space

Active cancellation

- Active cancellation could help solve some of these issues
- Can be optimised to maximise power efficiency, field fidelity and/or size. Holes or gaps in the system can be taken into account
- Promising weight reductions and increases the cancellation region
- Changes in external magnetic field can be accounted for to maintain a constant internal field, rather than the constant shielding factor given by passive shielding

P. J. Hobson et al. “Bespoke magnetic field design for a magnetically shielded cold atom interferometer”. Scientific Reports 12.10520 (2022).

Active shielding system

- Removed outer and heavier shield

- Active cancellation coils wound on a 3D printed coil former. Flexible PCBs can be used

- Quantisation axis bias field can be generated

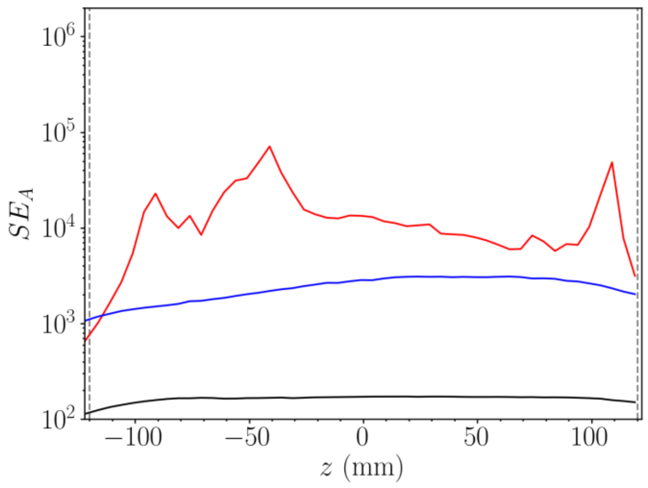
Science and Technology Facilities Council

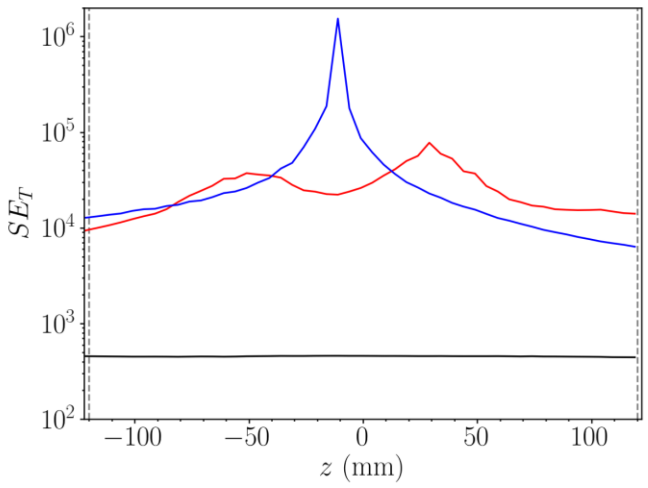
RAL Space

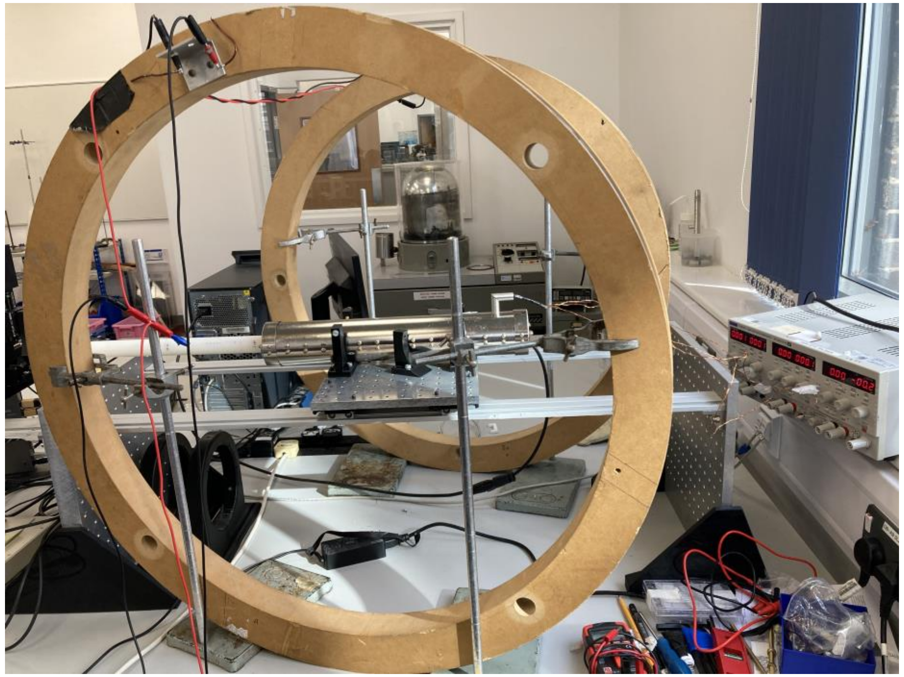
Characterisation of shields

- Magnetic fields were measured using a Bartington fluxgate magnetometer. Coils generate background magnetic field

- The shielding effectiveness of the passive system, is found to be over twice as poor as the active hybrid system







Setting	*SE*	SE_A	SE_T
One-layer passive shield	400	160	450
Two-layer passive shield	8,100	2,200	16,000
One-layer passive shield and integrated coils	18,000	7,800	21,000

Science and Technology Facilities Council

RAL Space

Conclusion

Increased efficiency

- 2x shielding factor averaged over optimisation region

Reduced weight

- ½ weight (5.5 kg → 2.3 kg)

Reduced volume

- 9.1 L → 1.9 L

Very low power consumption

- Power consumption of the whole system is < 1 mW

Documentation required

Documentation

All final deliverables shall be free of all commercial/confidential information, which should be provided under separate cover if necessary. No copyright nor dissemination restrictions shall be indicated.

Doc ID	Title	Milestone	No. of copies/format to be delivered to	e-copy to DMS (*)
(*) (**)	DMS (Data Management System) address: tecdms@esa.int. Please note that all finalised (i.e. reviewed and approved by ESA in their final version) documents resulting from a technology Contract shall be electronically sent by the Contractor to D/TEC's Data Management System (DMS) using the e-mail address tecdms@esa.int. This applies not only to the final documentation such as the Final Report or Summary Report but to all approved output documents (TNs, Progress Reports, etc.). See definition below the table.			
PH	Photographic Documentation	Final Review	Two electronic images/graphics files. All material should be free of copyright restrictions and ready to be used by to agency for communication activities towards the public. File to be delivered to the ESA Technical Officer.	no
FP	Final Presentation	Final Review	Electronic file in the form of a slide editor tool file (e.g. PowerPoint or compatible) to be delivered to the ESA Technical Officer.	yes
FPR	Final Presentation Recording	Final Review	A digital movie file between 1min and 3min length summarising the activity results. File to be delivered to the ESA Technical Officer.	no
ESR	Executive Summary Report (**)	Final Review	Electronic searchable, indexed and not encrypted PDF and native (WORD) file to be delivered to the ESA Technical Officer and Contracts Officer. In addition to the above, one (1) electronic searchable, indexed and not encrypted PDF and native (WORD) file shall be sent to the ESA Information and Documentation Centre – ESTEC Library (email: esa.ids@esa.int).	yes
FR	Final Report (**)	Final Review	Electronic searchable, indexed and not encrypted PDF and native (WORD) file to be delivered to the ESA Technical Officer and Contracts Officer. In addition to the above, one (1) electronic searchable, indexed and not encrypted PDF and native (WORD) file shall be sent to the ESA Information and Documentation Centre – ESTEC Library (email: esa.ids@esa.int).	yes

Science and Technology Facilities Council

RAL Space

Thank you

ralspace.stfc.ac.uk @RAL_Space_STFC RAL Space RAL Space