Design of magnetic shielding and field coils for a TES X-ray microcalorimeter test platform

Antoine R. Miniussi [a], [b], Joseph S. Adams [a], [b], Simon R. Bandler [a], James A. Chervenak [a], Aaron M. Datesman [c], William B. Doriese [f],
Megan E. Eckart [a], Fred M. Finkbeiner [a], [c], Richard L. Kelley [a], Caroline A. Kilbourne [a], Frederick S. Porter [a], John E. Sadleir [a],
Kazuhiro Sakai [a], [b], Stephen J. Smith [a], [b], Nicholas A. Wakeham [a], [e], Edward J. Wassell [a], [c], Henk J. van Weers [g], Wonsik Yoon [a], [e]

Contact : antoine.r.miniussi@nasa.gov

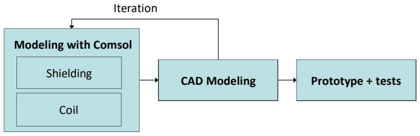
Requirement for the shielding

The performance of Transition-Edge Sensors (TES) and their SQUID multiplexed read-outs are very sensitive to the ambient magnetic field from Earth and fluctuations that can arise due to fluctuating magnetic fields outside of the focal plane assembly from the Adiabatic Demagnetization Refrigerator (ADR).

Thus, the experimental platform we are building to test the FPA of the X-ray Integral Field Unit (X-IFU) of the Athena mission needs to include a series of shields and a coil in order to meet the following requirement of magnetic field density and uniformity :

Requirement	Test platform	Athena/X-IFU	Achieve with
Maximum static DC magnetic flux density normal to <u>detectors</u> Bz	1 µT	1 µT	Shield
Uniformity across the <u>detector</u> plane ΔBz	0.1 µT		Coil
Maximum static DC magnetic flux density normal to <u>SQUID</u> Br	1.10^{-4} T		Coil
Uniformity across the <u>SQUID</u> plane ΔBr	1.10^{-4} T		Coil
Shielding factor Siz for internal field component normal to detector surface (ambient field/reduced field)	$> 10^5$	$> 10^5$	Shield
Shielding factor Sir for internal field component parallel to detector surface (ambient field/reduced field)	$> 10^3$	$> 10^3$	Shield
Detector radius	12 mm	12 mm	/

Process



Iteration

Modeling with Comsol

Shielding

Coil

CAD Modeling

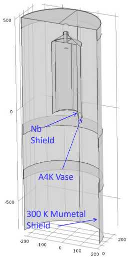
Prototype + tests

Comsol Modelling – Shielding

The magnetic shielding is comprised of 3 shields at different temperatures and shape in different materials:

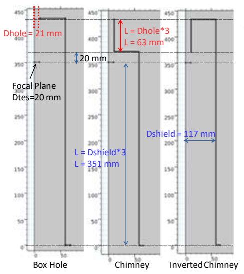
- **<u>Mumetal Shield</u>**: 300 K. Relative permeability=20 000. Split into 4 parts (hood, upper, lower, bottom) to fit the assembly design (space of 1-2 mm between the parts)
- **<u>A4K Shield</u>**: 3K. Relative permeability=10 000 (at LHe for 50 A/m field). Between the Mumetal shield and the Nb shield.
- **<u>Niobium Shield</u>**: 50 mK. Modeled as perfect superconductor (relative permeability=0).

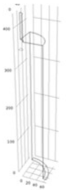
The niobium shield surrounds the TES focal plane. It is cooled down to 50 mK. At this temperature, the Nb is superconducting (below 9 K) which gives the best shielding against magnetic field. However, the niobium shield but can also trap flux.



Niobium Shield – Study of the shape

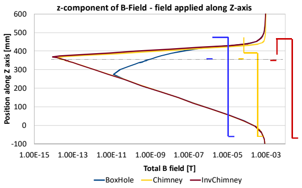
The TES array and its focal plane assembly are housed within a cylindrical Nb shield opened on both sides held at 50 mk. At each end, the same aspect ratio of length to diameter is applied to have equivalent shielding factor. The shielding is designed so that at each end: Length of the cylinder = 3*Diameter of the hole.





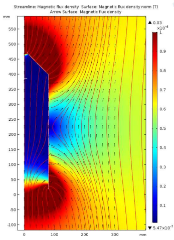
Chimney design in 3D

The design is constrained by the value of the z-component of the B-field applied along the Z-axis. Here we show a comparison of the different Nb shield shapes for an applied field of 1E-3 T.



➔ *Chimney* and *Inverted Chimney* designs are similar in term of magnetic shielding factor

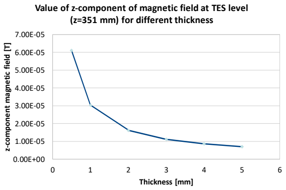
A4K Shield – Study of the material thickness



The modeling of multiples shapes for the A4K shield have lead to a specific design: a vase shape shield with smooth angle (no right angle) to allow the magnetic field to flow on its surface. See left figure.

We studied the impact of the thickness of the A4K on the magnetic field.

➔ A thickness of 1 mm seems to be a good compromise between stiffness (weight) and shielding factor



Modeling of the three shields

Since the *Chimney* and *Inverted Chimney* designs for the Nb shield give a similar shielding factor, we will use the *Chimney* design in order to have an easier assembly of the Nb and the A4K shields.

This model is run in two steps to simulate the transition from the normal state to the superconductor state of the Nb. (1) Residual magnetic field is calculated with the Mumetal and the A4K shields only activated. (2) The model is run again with the results from (1) and Nb shield activated.

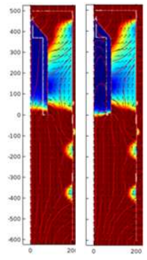
<u>The shielding factor – Z-axis</u> :

- 1st step: 380 (2.6E-6 T)
- 2nd step : 1.10^{11} (8E-15 T)

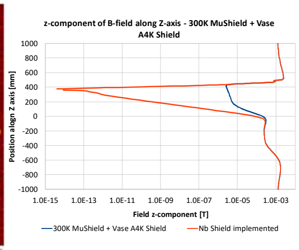
<u>The shielding factor – X-axis</u> :

- 1st step: 4200 (2.4E-7 T)
- 2nd step : 6.10^8 (1.7E-12 T)

➔ The stack of Mu metal, A4K and Nb shield leads to a shielding factor on both normal (Z) and parallel (X) components theoretically above the requirement (respectively 10^5 and 10^3).



1st Step 2nd Step

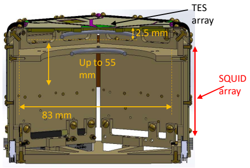


Comsol Modelling - Coil

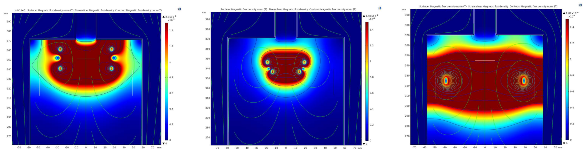
The residual magnetic fields trapped in the Nb shield are compensated with a coil near the TES to get the best field uniformity along the focal plane.

The best design of this field offset set up is a trade-off between the number of coils, their positions, their sensitivity to a tilt or displacement and the value of the field which reaches the SQUID readout devices surrounding (lowest value is the goal).

We modeled three types of coil : *Helmholtz*, *JAX* and *Single*. For each type, we calculated the position of the coil(s) to get the best uniformity of the field along the TES array and the impact of a 1 deg tilt of the coil(s) on it.



The coils are set under the TES to reduce the interaction between the Nb shield and the generated magnetic field.



Helmholtz coils **JAX coils** **Single coil**

The intensity range is the same for the three figures. Maximum value of the field is given on top-right.

	Helmholtz	JAX	Single
Z-comp of the mag flux – Value at TES center [T]	1.8E-5	2.2E-5	2.2E-5
Delta Field on TES [T]	6.3E-8	1.3E-8	1.8E-8
Ratio*	280	1650	1200
Ratio* for 1 deg rotation of the coil(s)	200	90	250
Impact on the SQUID – Maximum of the r-comp of the mag flux	4E-6	4E-7	2E-5

* Ratio is defined by : {mag flux at the center of the TES} / {Delta field across TES}

- The simple Helmholtz coils doesn't give a good ratio for the uniformity of the magnetic field
- The *JAX* coils have the best ratio and the most focused field (low impact on SQUID) but a small change in the position of one of the coils (or both) leads to a high degradation of the field uniformity
- The *Single* coil gives a good ratio with and without 1 deg tilt but bring a high magnetic field on the SQUID.

➔ The high sensitivity to a small change of position of the JAX coil as well as its higher complexity of mounting lead us to choose the Single coil design.

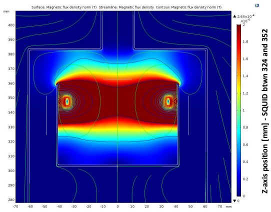
➔ The high impact on the SQUID is solved by the implementation of a SQUID shield

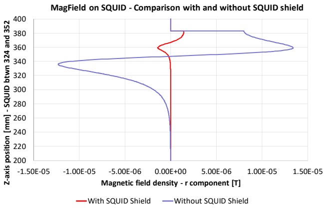
SQUID shielding implementation and final results

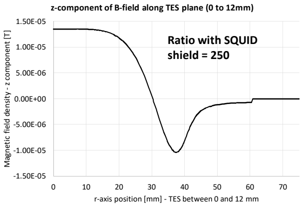
For one design (or position) of the Nb and/or SQUID shield there exists multiple positions of a single coil that meets the field uniformity requirements (ratio above 10). Designs iterations between the best coil position and the 3D CAD model gave us the best following results.

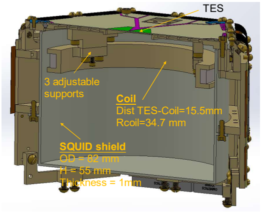
We took into account that (1) The shield has a OD of 82 mm, is placed 4 mm away from the TES and is 1 mm thick. (2) Space between the coil and the shield has to be greater than 4 mm. (3) A longer shield has less impact on the uniformity along TES plane.

The following plots shows the results obtained for the best position of the coil.









- SQUID shield reduces the magnetic field flux on the SQUID by a factor 100
- The uniformity ratio decreases from 1200 to 250
- A rotation of the coil of 1 deg with the SQUID shield decreases the uniformity by a factor 2
- The coil is mounted "close" to the TES support with 3 adjustable supports to avoid and correct misalignment

➔ This design with the given coil and SQUID shield positions and dimensions allows a good field uniformity along TES plane (ratio of 250) with a high shielding of the SQUID.

➔ The *Single Coil* design with its 3 supports is easy to mount and to adjust.

Conclusions

- We have modeled the magnetic shielding of the Mumetal, A4K and Nb shields as well as the coil using Comsol. The resulting design will be used to test the FPA of Athena/X-IFU.
- The theoretical results meet the requirements and give us confidence to build this setup.
- The CAD designs of the Nb, A4K and 300 K shields as well as the coil and SQUID shield sub-assembly are done.
- The fixation system of the Nb and A4K shields to the 50 mK and 3 K stages, respectively, is still under construction
- A shielding/coil prototype will be machined within the next few months

Affiliations

[a] : NASA Goddard Space Flight Center
[b] : CRESST II – University of Maryland Baltimore County
[c] : SGT, Inc
[d] : Wyle Information Systems
[e] : NPP – Universities Space Research Association
[f] : NIST – National Institute of Standards and Technology)
[g] : SRON – Netherlands Institute for Space Research

17th international Workshop on Low Temperature Detectors – July 2017