Optimised Hybrid Magnetic Shielding System Using The Streamfunction Method For CubeSat Applications

Abstract

The majority of emerging quantum technologies require strict control over their magnetic field environment for their successful operation, and many others for benchmarking (like quantum magnetometers). The best control over magnetic field environment can be achieved with the combination of intricate coil systems and high permeability magnetic shielding (known as hybrid magnetic shielding)[1]. When the coil system is not a simple geometry (like a plane or cylinder), their design becomes much more challenging. It is also challenging when designing a system that accounts for the interaction between the passive shielding and active coils[2]. Presented in this talk is a method utilising COMSOL Multiphysics which overcomes both challenges.

In this talk, a previously designed hybrid magnetic shield for a satellite-based application is used as an example and improved upon. The placement of the shielding material is limited by the shape of the equipment inside of it and the exterior cubic box it is housed in.We first optimise the shape of the passive shielding by using a simple quadratic deformation of the starting shield geometry and use COMSOL Multiphysics to evaluate how this affects shielding performance in terms of both Shielding Effectiveness (SE) and the shield's mass. The optimisation is shown to increase the SE by 24% in the central region and decrease the shield's mass by 30%.

To design coils that lie on the inner surface of this optimised shield, a stream function-based target field method is used [3]. Firstly, a Boundary PDE interface in COMSOL, is set up to calculate the eigenfunctions on the surface where we wish to design the coils. These eigenfunctions are then exported and used as the modes of the current's stream function. Each of these is then individually imported back into COMSOL, and the field they produce calculated. Once the field produced by these modes is found, we perform our optimisation routine which produces our coil designs. This process is performed using Livelink for MATLAB which makes the repetitive importing/calculating process used in our methodology feasible. Such coils are designed inside of a passive shield and accounting for the interaction with shield, but this methodology is flexible and also works for the design of coil systems that exist in free space.

This methodology allows for coils to not only be designed on arbitrarily shaped surfaces inside of passive magnetic shields, but also allows for straightforward design of coils with optical access constraints.

Reference

[1] P. J. Hobson et al., "Benchtop Magnetic Shielding for Benchmarking Atomic Magnetometers," in IEEE Transactions on Instrumentation and Measurement, vol. 72, pp. 1-9), Art no. 6007309, (2023), doi: 10.1109/TIM.2023.3293540

[2] M. Packer et al., “Optimal Inverse Design of Magnetic Field Profiles in a Magnetically Shielded Cylinder,” in Physical Review Applied. 14. 54004. (2023). Doi: 10.1103/PhysRevApplied.14.054004.

[3] A. Davis et al., “Bi-planar magnetic stabilisation coils for an inertial sensor based on atom interferometry,” Physics Open, 20, 100227. (2024). Doi:10.1016/j.physo.2024.100227

Figures used in the abstract

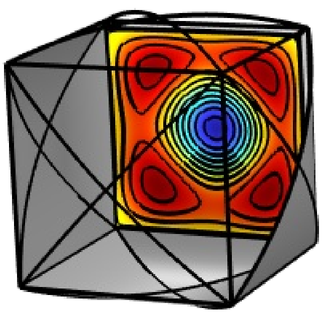

Figure 1 : An example of optimal coil designed using the streamfunction method inside of a passive magnetic shield.

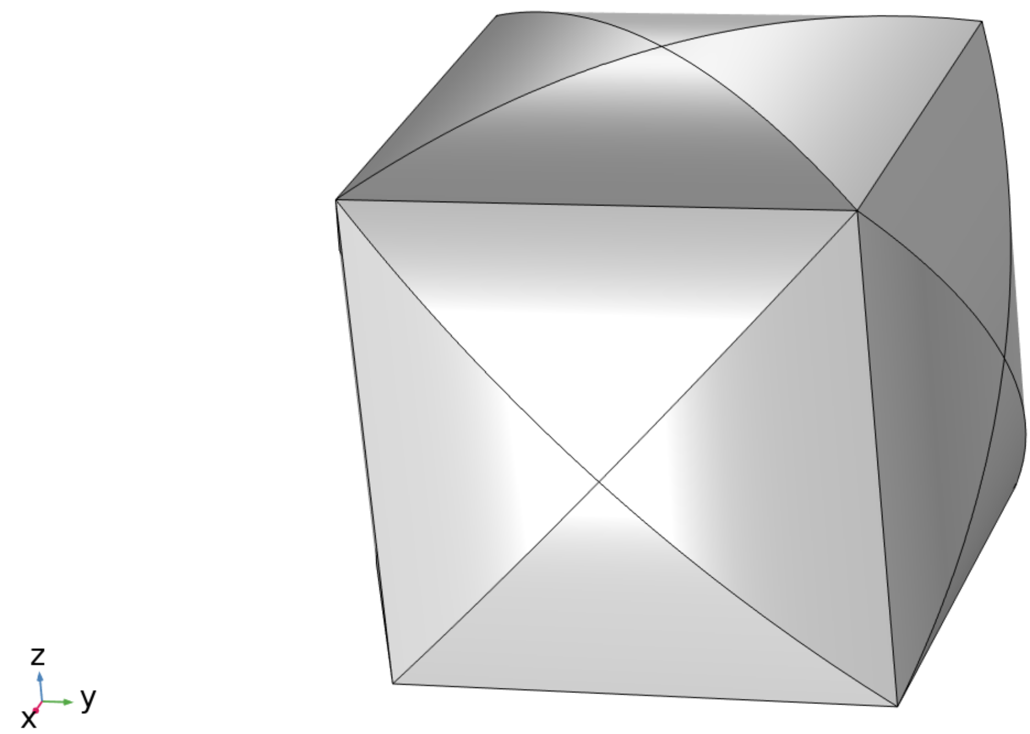

Figure 2 : Figure 1: A render of the deformed shield geometry. Created by quadratically deforming a cube.

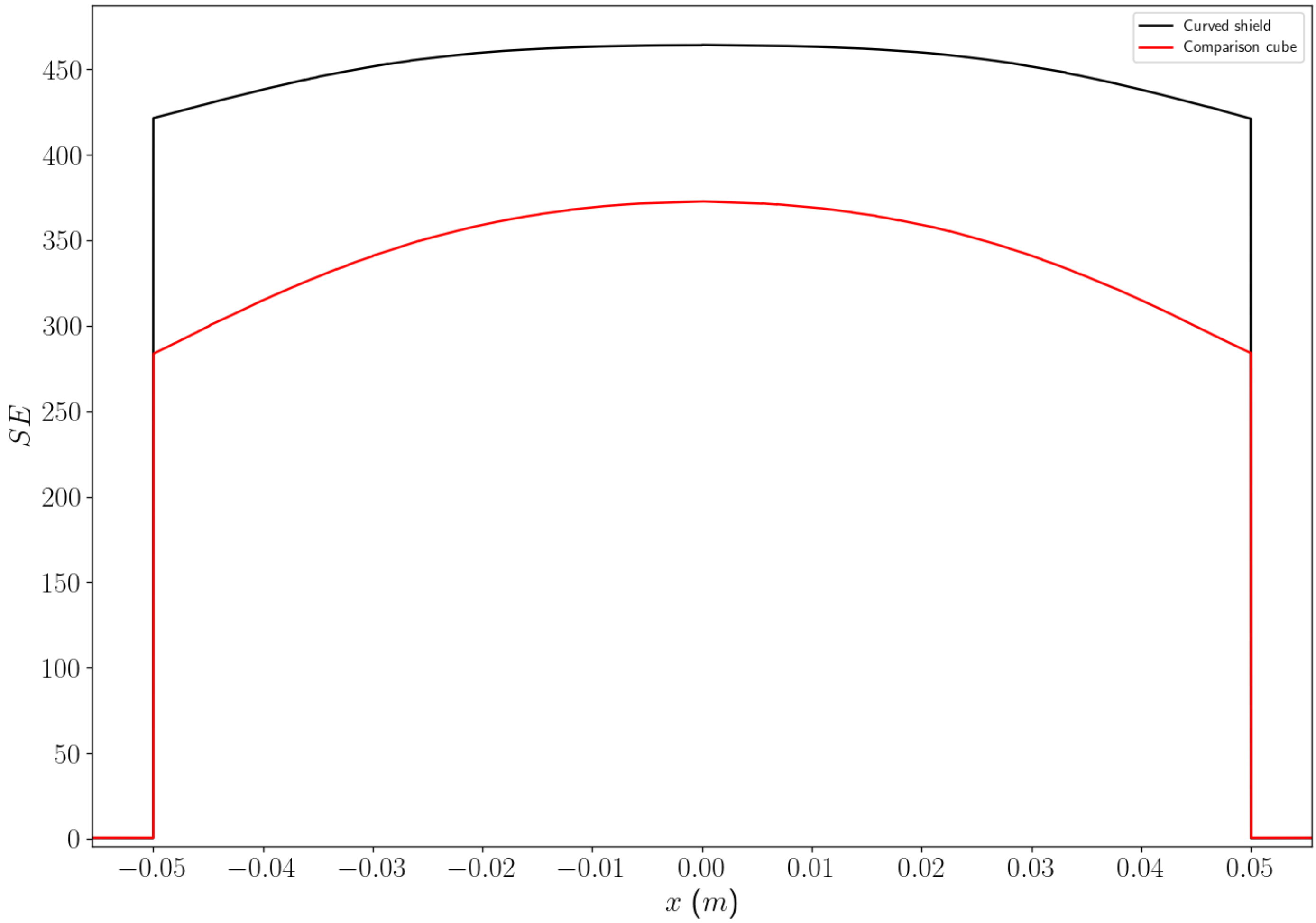

Figure 3 : Figure 2: A comparison of the Shielding Effectiveness (SE) along a central line inside the shield between the deformed shield and the cubic shield.

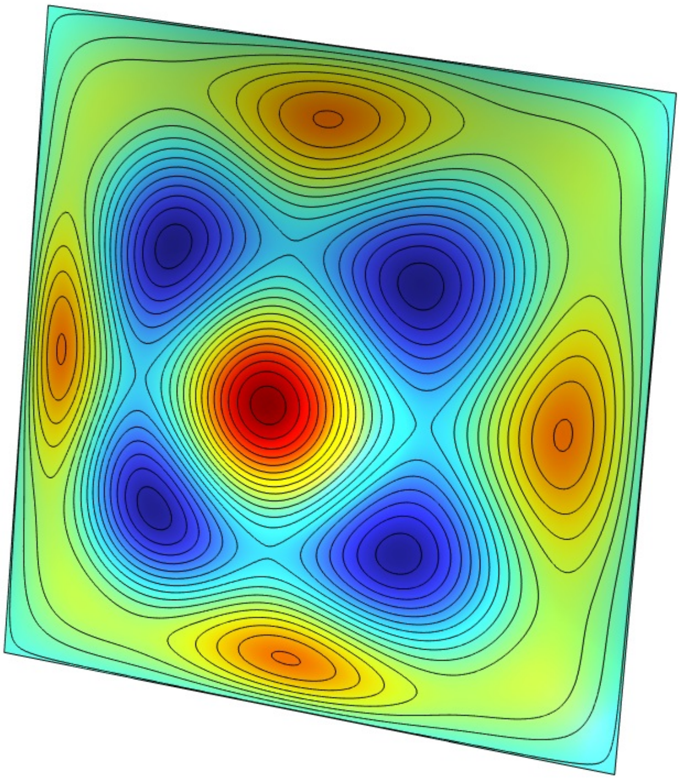

Figure 4 : Figure 3: An eigenfunction of the coil design domain, which is used to create to construct the current's stream function in the coil design process. The design domain is a panel interior to the shield's surface.