INTRODUCTION

To calibrate compact low noise gradiometers for ESA, measurement facilities are required that can provide both the low noise magnetic environment and apply the magnetic fields and gradients with the required uncertainty.

NPL are developing the facilities and capabilities needed, which include:

- Improved magnetic cancellation capability to reduce the magnetic noise of the environment down to 1 pT/Hz at 1 Hz from the existing 20 pT/Hz.
- Stability for noise measurement at a frequency of 0.1 mHz, which have been established using an existing 3 m diameter Helmholtz coil system and thermally isolated three layer mu metal can.
- Calibration facilities include the generation of a known gradient and a gradient coil standard has been designed.

NPL LOW MAGNETIC FIELD CANCELLATION SYSTEM

The Low Magnetic Field Laboratory is based in Bucky House on the NPL site in Teddington, UK. Unlike modern buildings, when built in 1883 no magnetic materials were used in the construction. As a consequence, the magnetic signature of the building is very small. This makes the building suitable for a low magnetic field laboratory based on coil systems to reduce the ambient magnetic field to the required level. The 3 m diameter Helmholtz Coil established is shown in Figure 1.

![Figure 1](image1.png)

Figure 1. 3 m diameter Helmholtz coil used to reduce the magnetic field. The calibration of the magnetic field variation shown in Figure 3 is the magnetic field variation used in the construction. As a consequence, the magnetic signature of the building is very small. This makes the building suitable for a low magnetic field laboratory based on coil systems to reduce the ambient magnetic field to the required level. The 3 m diameter Helmholtz Coil established is shown in Figure 1.

NEW GRADIENT FIELD STANDARD

When the sensors of magnetometers are configured to measure magnetic gradients, the calibration involves the generation of a known gradient. The calibration of the magnetic flux density scaling factor cannot easily be used since the separation (baseline) of the sensors will probably not be known to the required accuracy.

![Figure 2](image2.png)

Figure 2. Schematic showing the cancellation method used.

Shown in Figure 3 is the magnetic field variation in the laboratory before and after cancellation. The origin of the variation with time before the cancellation system is operated are mainly due to the electrical lines used in the area. The electrical return of the circuit is not insulated and so earth leakage currents are generated causing a variation mainly in the vertical component. These currents then produce the very small magnetic fields shown in Figure 3. Other sources of disturbances in the ambient magnetic field are from the Earth’s daily diurnal variation, ‘Sun Spot’ activity and the effect of vehicles and other nearby ferromagnetic items.

As more sensitive magnetometers are developed, the noise floor needs to be lowered to 1 pT/Hz. This will be achieved by using an auxiliary coil to close the feedback loop and atomic magnetometers to lower the measurement noise floor from the 1 pT/Hz currently achieved using fluxgate magnetometers.

![Figure 3](image3.png)

Figure 3. Mag-03 three axis fluxgate magnetometer.

To make noise measurements at less than 1 Hz a three layer mu metal can has been used. This is placed inside the cancellation system shown in Figure 1. Any slow variation of the magnetic field produced in the low magnetic field laboratory before the feedback has been closed are then removed. The arrangement is shown in Figure 4.

![Figure 4](image4.png)

Figure 4. Gradient coil for the calibration of gradiometers.

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NOISE MEASUREMENTS AT 0.1 mHz

To make noise measurements at less than 1 Hz a three layer mu metal can has been used. This is placed inside the cancellation system shown in Figure 1. Any slow variation of the magnetic field produced in the low magnetic field laboratory before the feedback has been closed are then removed. The arrangement is shown in Figure 4.

The temperature coefficients of the magnetometers that require the noise floor measured at 0.1 mHz is such that the temperature needs to be stable for the 10000 seconds it takes to perform those measurements (more than 7 cycles). If this is not achieved, then low frequency noise artefacts will appear in the Power Spectral Density analysis. If this is not achieved, then low frequency noise artefacts will appear in the Power Spectral Density analysis.

Shown in Figure 5 is the gradient tensor that needs to be determined. For the ESA gradiometer it is necessary to calibrate 5 of the 9 terms. To achieve this, both diagonal and off diagonal terms will be produced using the gradiometers shown in Figure 6. This can will be calibrated be using currents that are large enough to produce magnetic fields that can be measured with a calibrated Hall probe.

![Figure 5](image5.png)

Figure 5. The magnetic gradient tensor to be measured.

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The remote reference magnetometer is used to cancel the fixed component in that direction. The smaller time variations are removed by adjusting these currents using an identical magnetometer in the main laboratory. This magnetometer is removed during calibrations.

Using this approach a noise floor of 20 pT/Hz is achieved.

![Figure 6](image6.png)

Figure 6. Gradient coil for the calibration of gradiometers.

Improved magnetic cancellation capability to reduce the magnetic noise of the environment down to 1 pT/Hz at 1 Hz from the existing 20 pT/Hz.

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![Figure 7](image7.png)

Figure 7. PSD of a 0.1 mHz for noise evaluation at 0.1 mHz.

It can be used from Figure 7 that at 0.1 mHz the noise is approximately 420 pT/√Hz. To establish a mean value and an uncertainty on the noise measurement repeated to be performed a number of times. Using 15 runs, the noise is 475 ± 220 pT/√Hz. These measurements were performed using a Bartington Instruments Mag-03 three axis fluxgate magnetometer. Measurements for each of the three axes indicate that the noise behaviour shown in Figure 7 is limited by the magnetometer noise and not the environment noise.

SUMMARY

- Low Magnetic Field Laboratory based at the NPL Teddington site, UK, achieves a noise floor of 20 pT/Hz at 1 Hz.
- Work is underway to lower this to 1 pT/Hz for the calibration of new ultrasensitive magnetic field sensors.
- DC magnetic field capability offering uncertainties as low as ±0.05 % available.
- Gradient coil based on a modified Maxwell pair to be used to calibrate gradiometers.
- Low Magnetic Field Facility used to establish a method for the measurement of the noise of magnetometers at 0.1 mHz.

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National Measurement System

MAGNETIC ENVIRONMENT AND MEASUREMENT SYSTEMS FOR THE CHARACTERISATION AND CALIBRATION OF LOW NOISE MAGNETOMETERS AND GRADIOMETERS

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Working in partnership with:
Rutherford Appleton Laboratory
Space Science and Technology Department
Bartington Instruments Ltd.