The importance of magnetic cleanliness and in-flight compensation to account for fluctuations in magnetic fields is a recognized concern within the space industry. Effects from stray magnetic fields must be considered, minimized and compensated for throughout the development of spacecraft and their subsystems. Within the context of the Laser Interferometer Space Antenna (LISA) Pathfinder mission, the sensitive telemetry systems needed to detect gravitational waves are vulnerable to magnetic disturbances.

**Compact Low-Noise Fluxgate Gradiometer**

The CLNG in Fig. 1 is capable of measuring both magnetic flux density vectors and gradient sensors using just five of the nine possible fluxgate sensors within the compact low-noise gradiometer prototype.

**Shielding and field cancellation**

Fluctuations in ambient magnetic field must be minimised to evaluate the noise performance of the CLNG prototype at 1 Hz to 0.1 mHz. A three-layer mu metal can was used, which was placed inside a 3 mm diameter triaxial Helmholtz coil system, where noise contributions from the ambient magnetic field were already reduced to 20 pT/Hz at 1 Hz. Insulation between layers of mu metal and surrounding the entire can also reduces thermal drift to 0.05 °C over 20 hours.

Measurements such as those in Fig. 2 were repeated using a commercial magnetometer over 15 runs to determine the mean value and estimated uncertainty of (475 ± 220) pT/±Hz at 0.1 mHz.

**Calibration of diagonal terms**

To calibrate the two diagonal components of the gradient tensor, the coils of the gradient coil were configured so that the current in each flowed in the same direction. This configuration is similar to a Maxwell pair, optimized to produce a gradient uniformity similar to that of Fig. 3 and used to determine the gradient sensitivities shown in Fig. 4.

**Calibration of off-diagonal terms**

The gradient coil was also configured in series opposition to form a poor Helmholtz coil, generating gradients in Bx along the Y axis as shown in Fig. 5 and Fig. 6. Since the gradient uniformity is not uniform when the coil is configured this way, the calibration uncertainty will increase, but such profiles allow off-diagonal terms to be calibrated.

**Summary**

- A range of technologies were combined to provide a comprehensive facility for calibration of compact gradiometers, such as that developed under ESA contract reference AO/1-6085/09/NL/AF.
- Passive shielding, field cancellation and thermal insulation were re-used to create stable near-zero field environments, in which the noise performance of commercial magnetometers and gradiometers have been assessed.
- A method for determining both diagonal and off-diagonal terms was developed, which uses a single gradient coil configured as either a Maxwell pair or Helmholtz coil (with poor uniformity) to generate known gradients.
- Parameters such as gain and gradient sensitivity for the CLNG were characterized using a combination of NPL’s existing triaxial gradient coils used to generate known diagonal and off-diagonal gradients within a magnetically stable environment. These technologies were combined to establish key parameters such as low frequency noise, offset, gain and gradient sensitivity, with specific attention given to the off-diagonal terms of the gradient tensor matrix.

**Acknowledgements**

The authors would like to thank the European Space Agency for their support under contract AO/1-6085/09/NL/AF and the National Measurement System of the Department for Business, Innovation and Skills that provided funding to develop the NPL low magnetic field facility.