



Experiences In Maintaining a Stable Variometer Temperature in a Small Enclosure

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ABSTRACT Historically, geomagnetic observatories have housed variometer instruments in large volume, well-insulated buildings or enclosures. With the move from optically recorded instruments to digitally recorded modern fluxgate magnetometers, the requirements of the enclosure have also changed. No longer is it necessary to maintain such large volumes to the same accuracy of temperature and there is a potential for significant cost savings in scaling down the enclosure and using modern heaters and heating controllers to stabilise the temperature.

BGS has conducted some initial tests on the suitability of heaters and heating controllers with the intention of then developing a small, easily deployable variometer enclosure to be used in place of existing observatory buildings, or for new observatories. However, small enclosures place the heaters, controllers and magnetometers in close proximity and here we show some of the problems encountered and solutions formed in these early stages of development.

INTRODUCTION

The three BGS observatories in the United Kingdom were built between 1904 and 1957 - a time when variometers used optical recording and required daily manual intervention. As a result, the buildings housing the variometers are large and very well insulated against external temperature variations. Today, the buildings continue to provide a good operating environment for modern variometers, but they are oversized for the instruments they contain and are expensive to heat and to maintain. Neither are these buildings a good model for new installations, where construction costs and deployment time are a priority and space and manual access are no longer as important.

BGS has begun to develop an alternative enclosure with an internal volume less than 2 m³; more suited to modern instrumentation, cheaper to deploy, operate and maintain. One of the consequences of reducing the size of the enclosure is that the heaters and heating controllers are placed in close proximity to the fluxgate sensor and electronics. Consequently, this creates specific problems that are not of concern in larger enclosures - radiant heating of the instruments, magnetic contamination, magnetic and electro-magnetic interference.

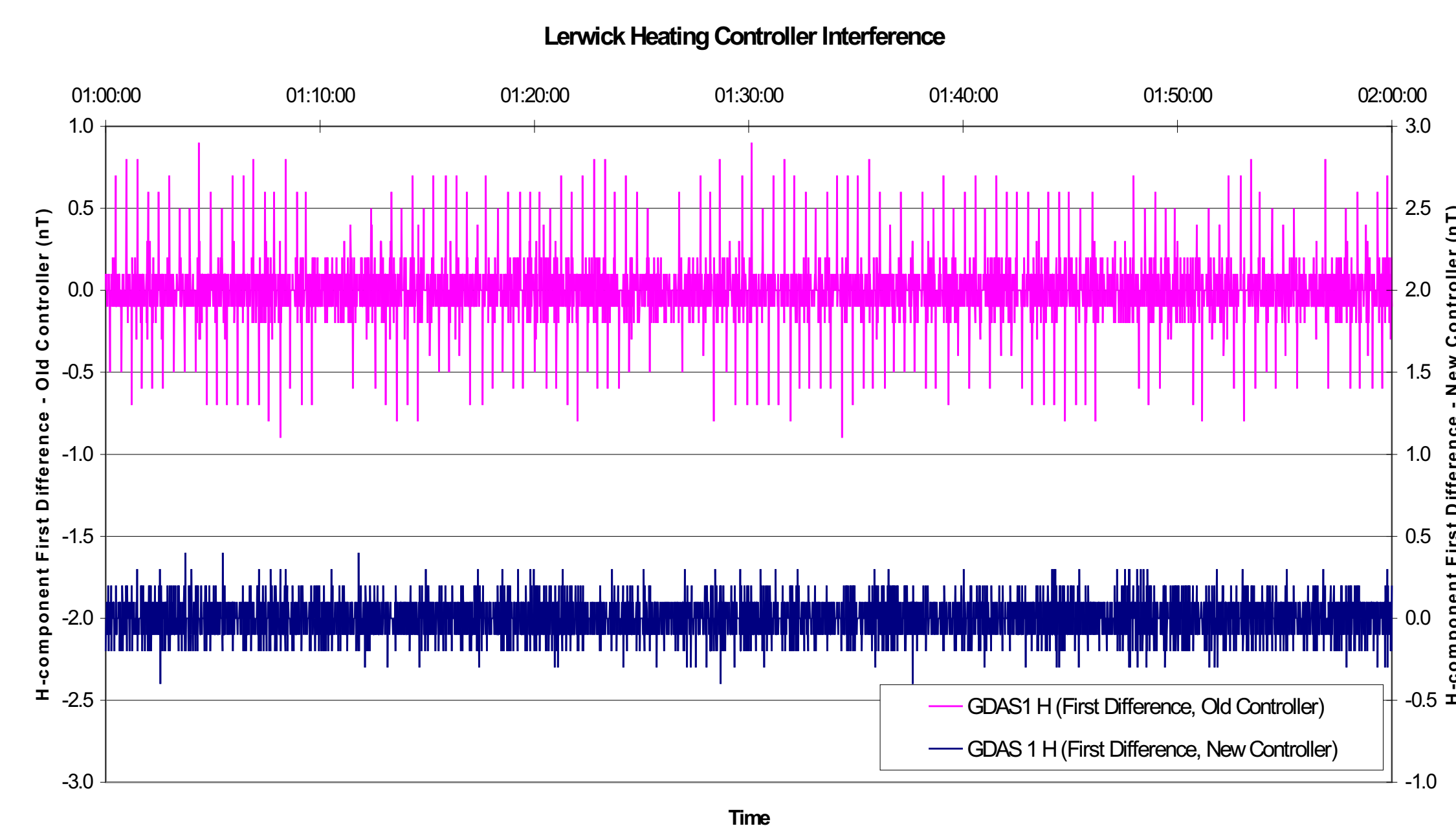
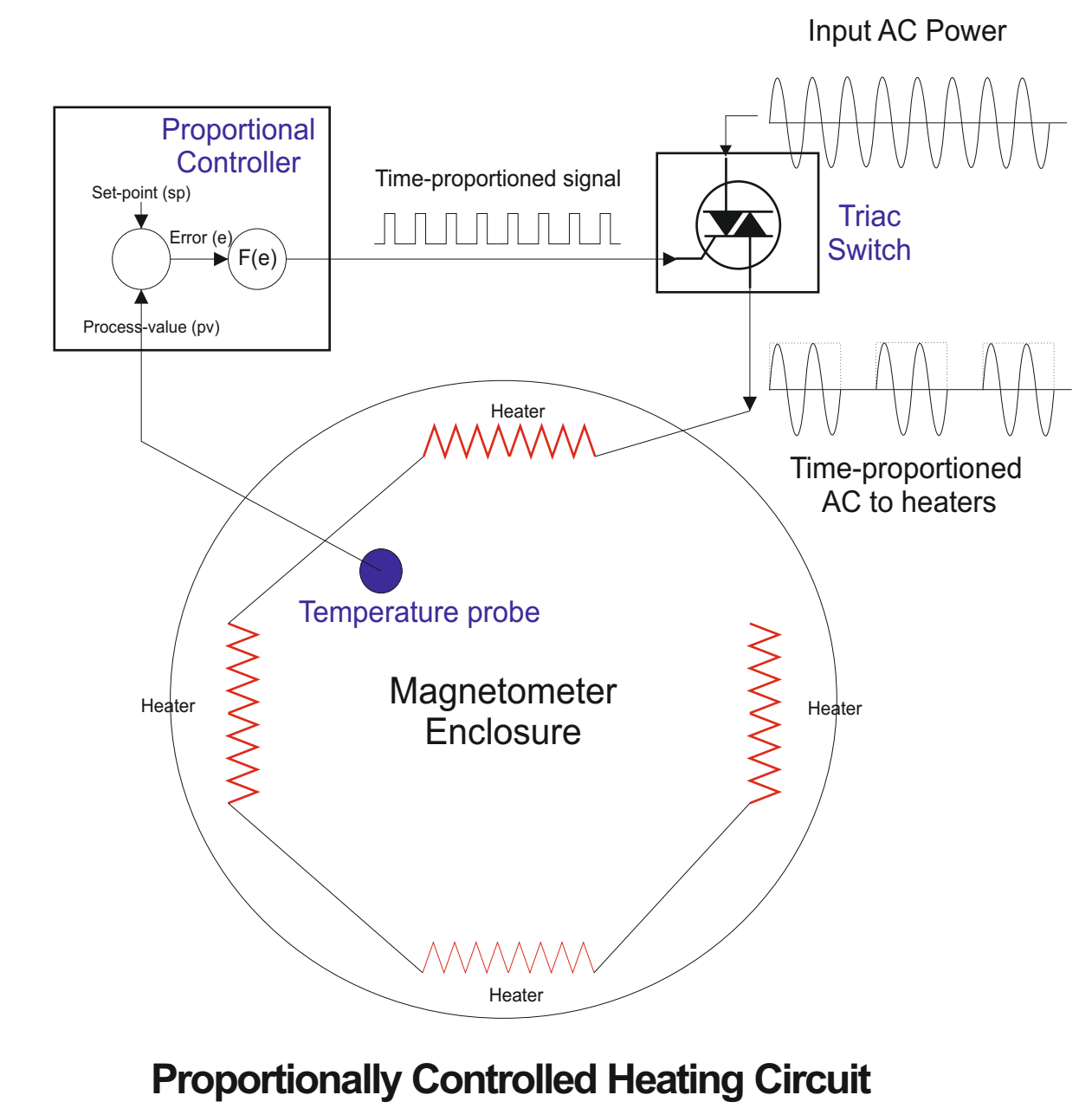
Radiant heating can be reduced to an extent by creating baffles between the heaters and the instruments and magnetic contamination and gradients are reduced by careful selection of materials, so here we look at some of the more subtle problems encountered in the early stages of development - namely magnetic and electro-magnetic contamination generated by the heating circuits.

The typical heating control system at a BGS observatory is based around a proportional controller, which regulates the electric power delivered to a bank of heaters as a function of the difference between the desired set-point and the measured enclosure temperature. When the enclosure temperature is outwith a defined band of the set-point, the controller operates in a similar fashion to a thermostat i.e. fully on or off. When the temperature is within the set-point band, the power to the heaters is smoothly time-proportioned between 0 and 100% in relation to the difference between the enclosure and set-point temperatures. This type of control is very effective at reducing the over-shoot and under-shoot hysteresis effects normally exhibited by cruder control devices such as thermostats.

The time-proportioned output signal from the controller is input to a triac, which gates the mains voltage to the load. The controller switches on the AC supply at the point of zero voltage, while the triac ensures that power is switched off at the point of zero current. Hence, the output comprises of full or half AC cycles, eliminating current steps and minimising noise.

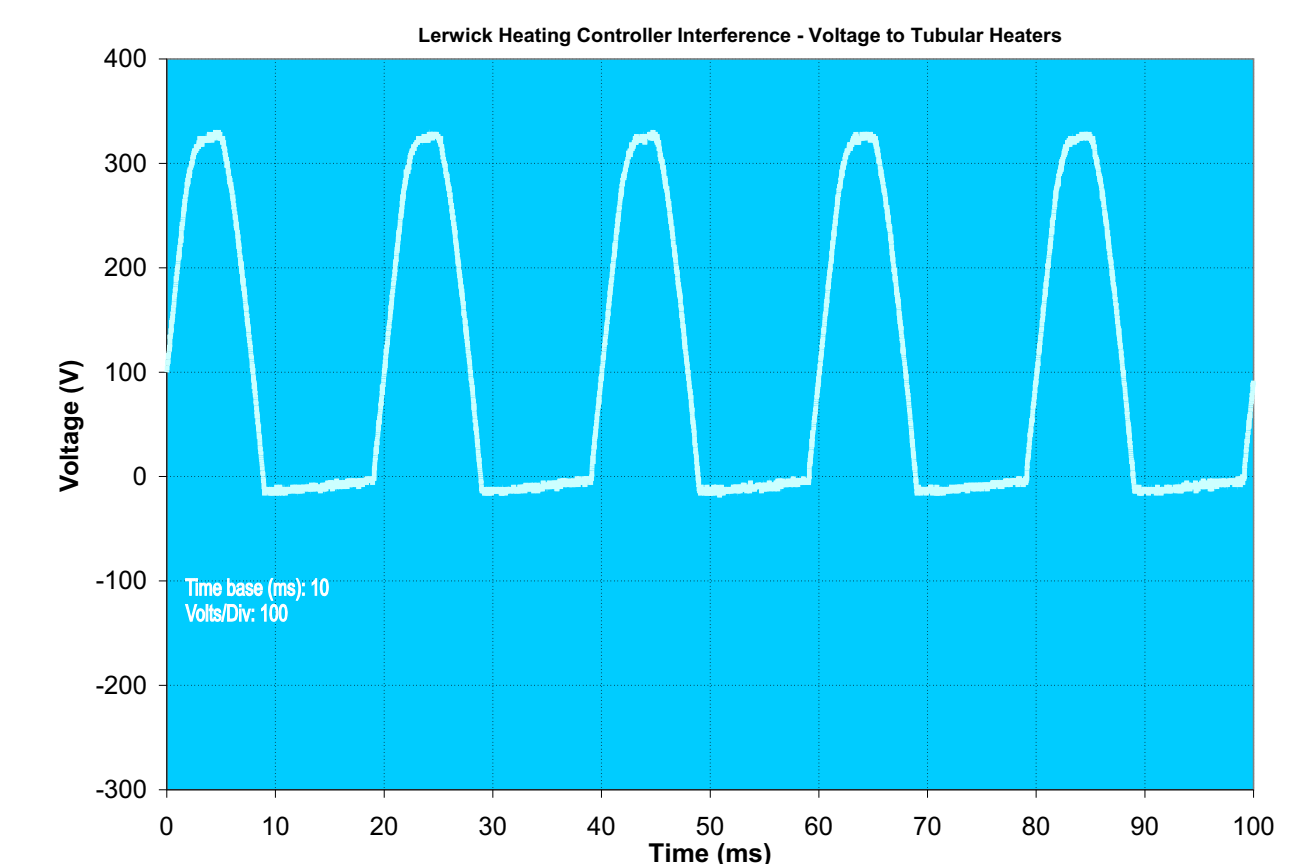
Specifically, we have introduced a three-term PID controller, where the control parameters are tuned specifically to the enclosure and can be set to adaptively change in response to changes in the operating environment, such as heating power available and thermal loss of the enclosure. The enclosure temperature is measured using a high-precision platinum resistance probe, capable of resolving to 0.01 °C and of little long-term drift.

In large enclosures, banks of 1.3 m long tubular heaters have typically been used as the heat source. Although these heaters contain solenoidal heater elements, because they are powered with a 50 Hz AC supply it has been assumed that the effect on the fluxgate magnetometers is negligible. Here, we show that when the heaters are placed in close proximity to the magnetometer in a small enclosure, these effects can be significant and must be considered in the design of the heating system.



Heating Controller Generated Interference

The plot on the left shows the first differences in the H-component output of a fluxgate magnetometer at Lerwick Observatory, sampled at 1 Hz over a two hour period. The upper trace clearly shows interference in the fluxgate magnetometer data, while the lower trace shows the same comparison after the heating controller was replaced. Hence, the controller was identified as the source.



The temperature in Lerwick is maintained by a PID controller and a bank of tubular heaters, the power to which is regulated by the controller via a triac. Measurements showed that, although there was no interference generated while the controller powered the heaters, the interference became evident while the power to the heaters was switched off. The time-series plot (on the right) shows the supply voltage to the heaters while power to the heaters was switched off. Despite the power being switched off, there remained a half-wave rectified component of the 220 VAC, 50 Hz electricity supply, produced by a breakdown in one of the triac gated diodes. This produced a DC component to the heater supply current and, since the heaters are solenoidal, there was a DC component to the generated magnetic field and resulting interference on the magnetometer.

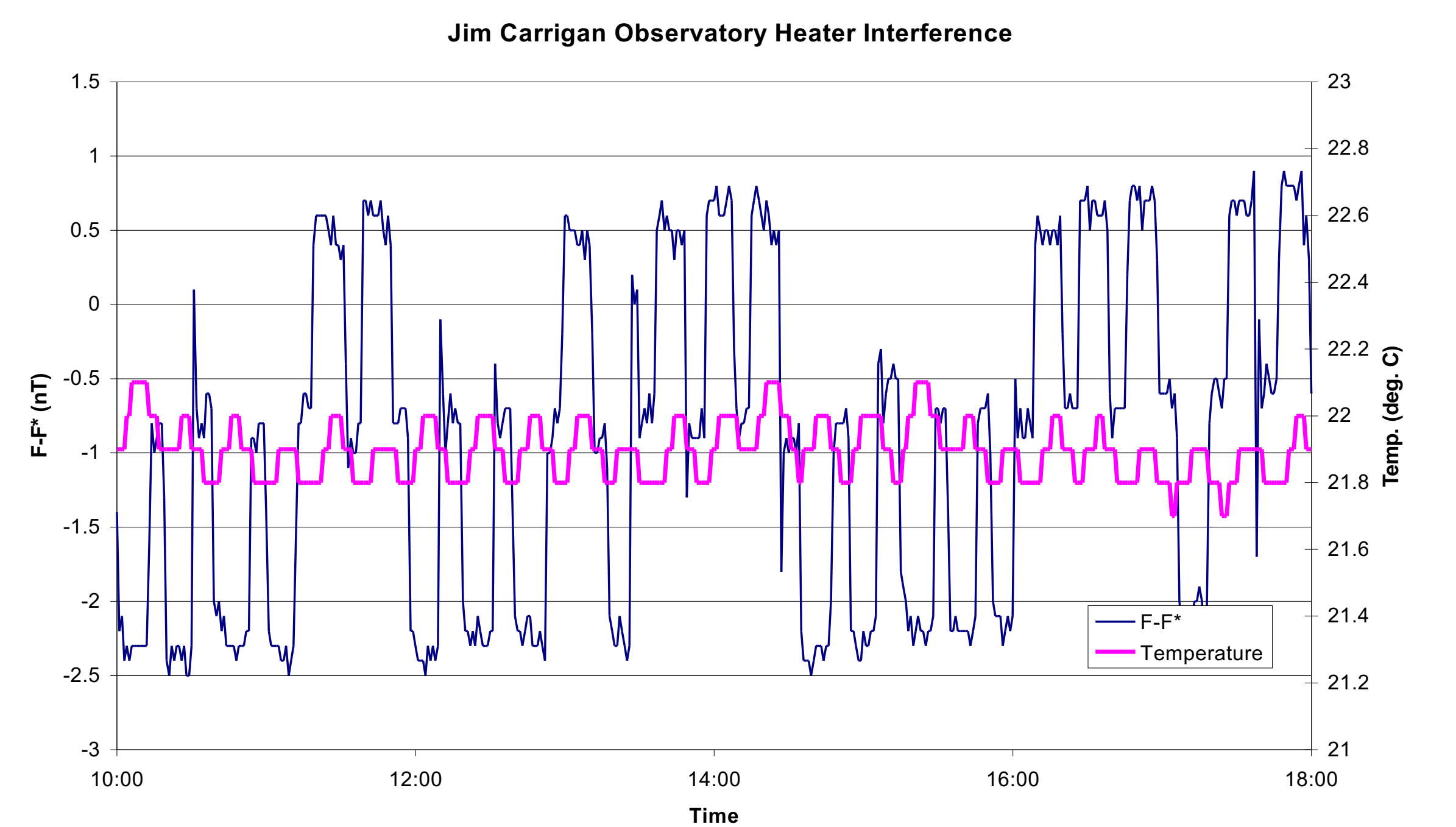
In this case, there was an obvious fault and consequence in the fluxgate magnetometer data, but it highlights a potential problem in the use of AC current and tubular heaters - if the AC wave is not exactly balanced, either directly from the electricity supply or due to an imbalance in the triac circuit, there will be a DC component to the magnetic field, which will be destroyed and created as the heating circuit is switched on and off.

Heater Generated Interference

The plot on the right shows a comparison between total field measured by the fluxgate magnetometer and the proton magnetometer (F - F*) at Jim Carrigan Observatory. The plot shows a mean offset of approximately -1 nT in the comparison, from which the fluxgate magnetometer data steps by 1.5 nT. The steps are randomly in phase or in anti-phase with the switching of the heating system, shown by the temperature trace in the plot.

Here, the temperature is maintained by tubular heaters controlled by a simple thermostat. The interference on the fluxgate magnetometer was traced to the design of the heaters and small components of ferromagnetic materials in the heaters and fixings. While the power was switched to the heaters, the solenoidal heaters drove the magnetisation of the ferromagnetic material positive and negative at a frequency of 50 Hz. This is outwith the measurement band of the fluxgate magnetometer, hence the stable centre value in the comparison. However, when the power was removed, the ferromagnetic material retained a remnant magnetisation. The sense of the magnetisation being determined by the sense of the 50 Hz supply at the moment the power was turned off, leading to a positive or negative step in the comparison about the centre value.

Ideally, all ferromagnetic material would be removed from the vicinity of the magnetometer, heaters and enclosure, but this is not always practical and any remaining material is often assumed to have a DC effect that is corrected for in the calculation of variometer baselines from absolute observations. This result shows the problem of using solenoidal heaters in close proximity to the magnetometer as well as the unstable influence of ferromagnetic material.



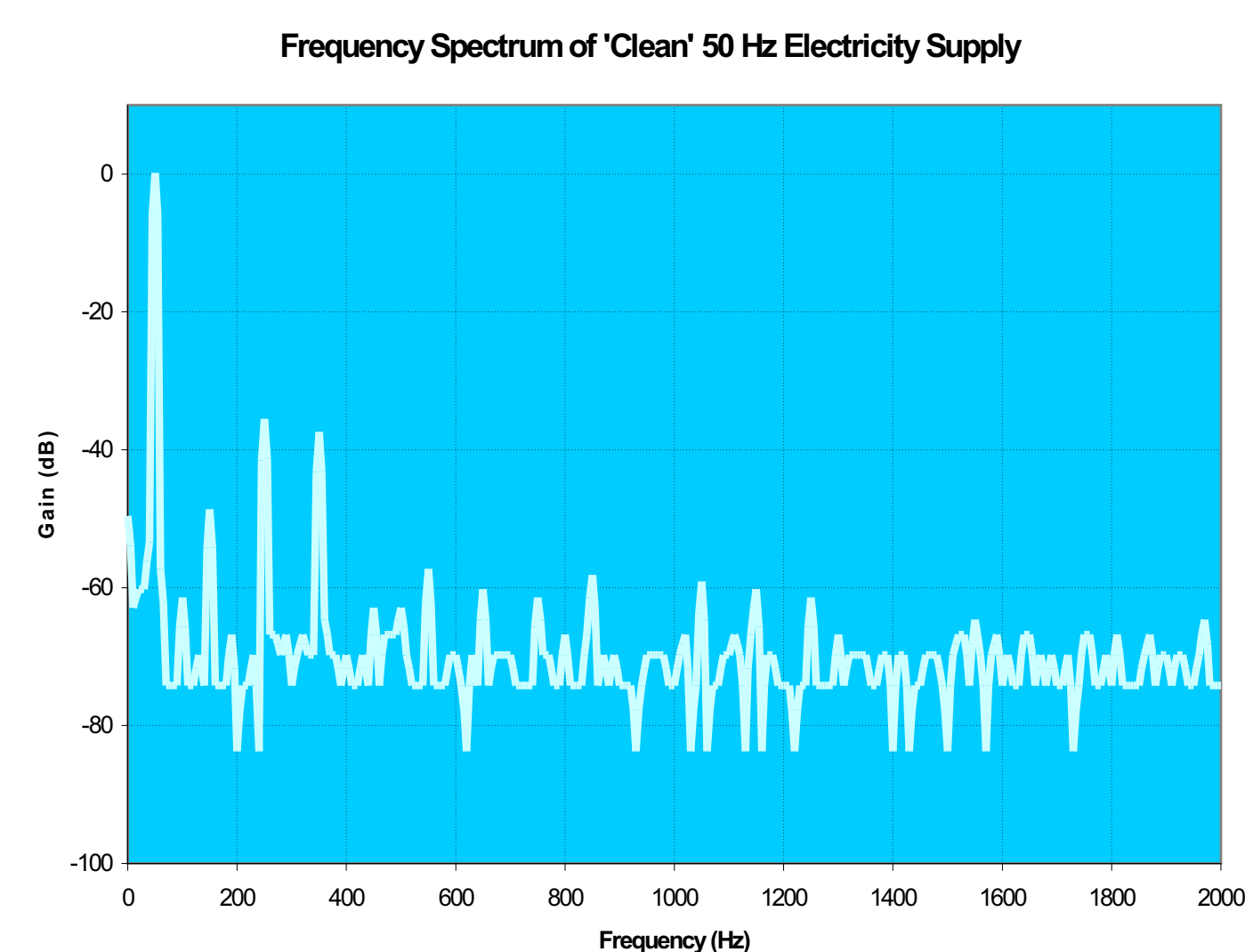
Electro-magnetic Interference

Experience at Port Stanley Observatory has shown that fluxgate magnetometers can be susceptible to radiated electro-magnetic interference from external sources. Port Stanley Observatory is located close to a number of high-power RF antennas and the effect of the transmission is measurable on both the fluxgate magnetometer used for variometer measurements and the fluxgate-theodolite used for absolute measurements. It is thought that interference is picked up in the sensor head or sensor cable and is of sufficient amplitude that a significant signal is output from the filter stage and input to the phase-sensitive detector. This is then manifested as a DC-offset in the fluxgate magnetometer output related to the amplitude of the interfering signal.

This effect is exacerbated when the interfering signal is within the pass band of the filter stage i.e. close to the second harmonic of the fluxgate magnetometer's excitation frequency. Since there is a potential for electro-magnetic coupling between the heating circuit in a small enclosure and the fluxgate magnetometer, tests were carried out to ascertain the effect. The plot on the left shows the frequency spectrum of a 'clean' 50 Hz 220 VAC supply powering a bank of tubular heaters. There are significant harmonics of 50 Hz at frequencies up to 350 Hz, while higher order harmonics, particularly those close to the 800 Hz second harmonic of the DMI FGE Ver.D fluxgate magnetometer are evident but are greatly attenuated in comparison.

Not surprisingly, this level of interference is too small to be detectable at the output of the fluxgate magnetometer's filter stage above the natural signal, even when tested with a bank of five 240 W tubular heaters within 1 m of the fluxgate sensor. Nonetheless, it is still considered to be a potential problem that could be made worse by noise in the mains supply i.e. interference induced elsewhere on the mains supply or an imbalance in the heating switching circuit as described above.

Electro-magnetic coupling between the heating circuit and the fluxgate magnetometer is likely to be minimised by changing the tubular heaters for a heater less efficient at radiating electro-magnetic interference. Later version of the DMI magnetometer have a higher excitation frequency (1.6 kHz), so will be more resilient to mains interference in this bandwidth, but will nonetheless be susceptible to noise around 3.2 kHz.



Along with the replacement of the heating controller at Lerwick, all of the problems described above have been solved by replacing the tubular heaters with infra-red bulbs (photo left). These bulbs have very little ferro-magnetic material, but more significantly, the geometry of the heating element is such that the bulbs do not generate a large magnetic field, nor do they efficiently couple electro-magnetic radiation into the fluxgate magnetometer. A set of these bulbs has been installed in a small enclosure with a fluxgate magnetometer for long-term testing at Eskdalemuir Observatory (photo right). Initial tests have verified that there is no discernable interference from the heating system and the next stage in the development is to produce a prototype of an insulated enclosure. The parts list of the equipment on test is:

- Eurotherm 2404 PID Controller
- Eurotherm TE10S Solid State Relay (Triac)
- Eurotherm Pt100 High-precision Temperature Sensor
- Exo-Terra IR Ceramic Heat Lamps PT-2048 (250 W)

