Cryo-Facility performance and Upgrades

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Contents

1 Introduction and scope

This report describes the performance of the SPIRE cryogenic test facility and the modifications needed for the final flight model test campaign.

The test facility comprises the following elements

- Dedicated Liquid Helium Cryostat
- Cryogenic Blackbody Source
- FIR Laser
- Test Fourier Transform Spectrometer (TFTS)
- Test Facility Control System (TFCS)
- Class 1000 clean room
- Control Room

The document differs from the other test reports for the SVR in that verification of instrument requirements are not addressed directly. Instead, the report will address the test facility performance requirements as defined in SPIRE-RAL-PRJ-000463. Details of the performance of the telescope simulator and TFTS are described in SPIRE-RAL-NOT-002006.

2 Facility Performance

2.1 Cryostat

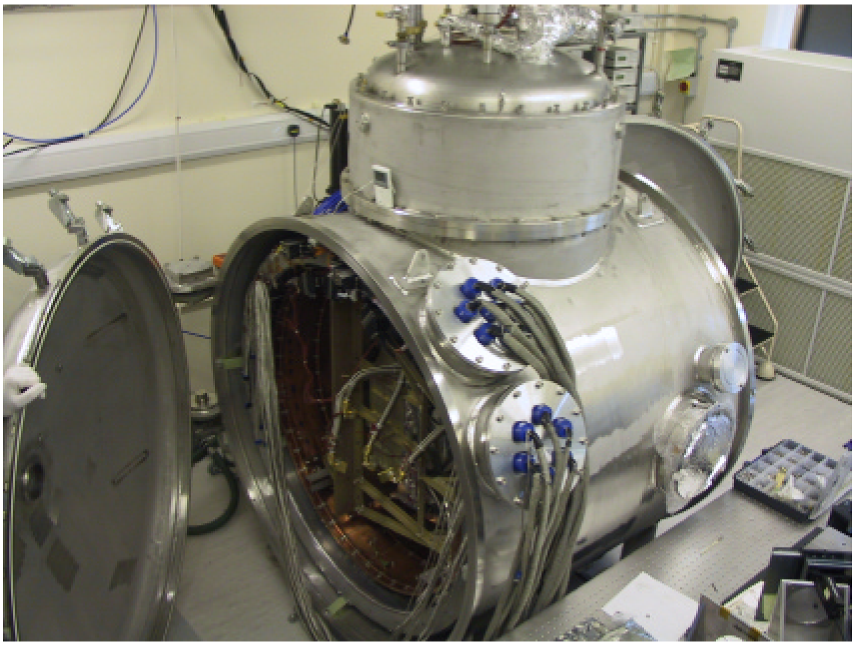


Figure 1. SPIRE Calibration Cryostat

The SPIRE Calibration Cryostat was designed to provide a representative thermal vacuum environment for thermal and performance testing. The cryostat has four stages of cooling, an outer liquid nitrogen cooled vessel at 77K, a 10K radiation shield, a 4.2K liquid He vessel and a 1.7K pumped liquid He pot. . The external calibration sources are viewed through a series of filters that reduce the thermal loading on the FPU.

Since delivery in January 2003, the cryostat has been cooled down 7 times including the two CQM campaigns and the first two PFM campaigns. A further 5 cooldowns are anticipated including the final flight model verification and calibration campaigns and the flight spare testing.

2.1.1 Pump-Down

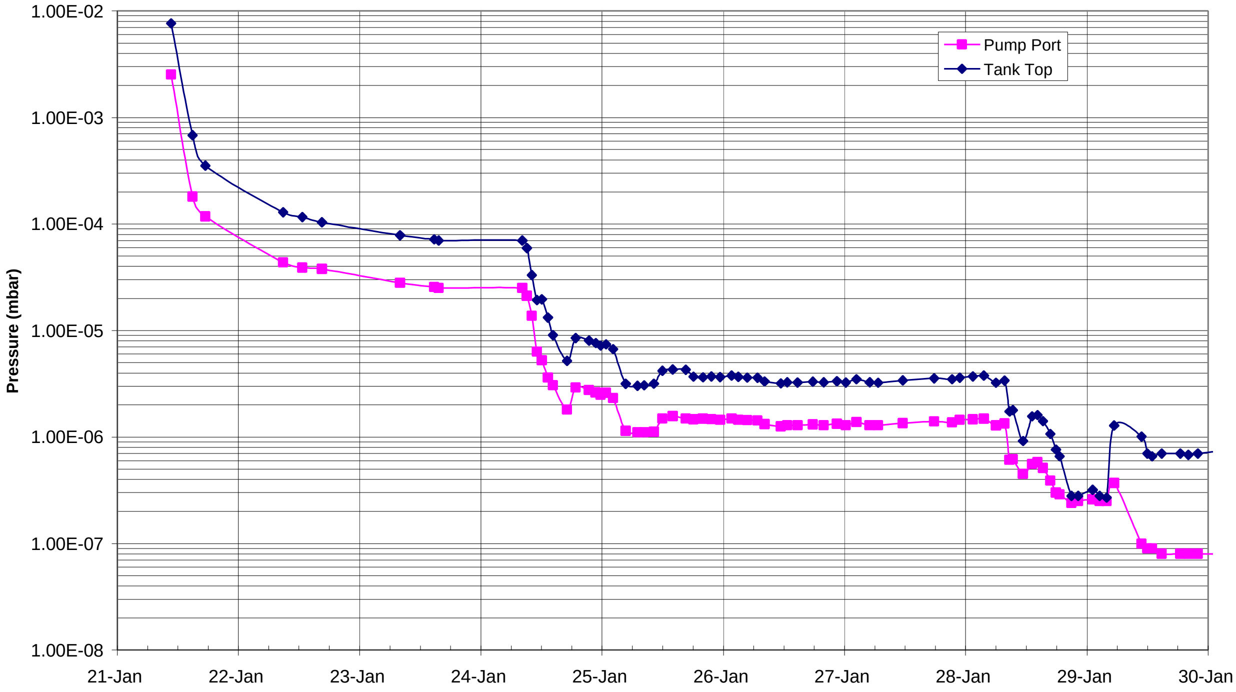


Figure 2. Cryostat pump-down plot for CQM-2 cold verification test campaign.

The SPIRE test chamber typically achieves a vacuum of 5x10^{-5} mbar after pumping for 48 hours. After introducing LN2 into the system, a vacuum of 3x10^{-6}mbar is typically reached. With liquid helium the pressure varies from 10^{-5}mbar to 10^{-6}mbar depending on whether the cryostat is being filled and the temperatures of the shroud and pipe work.

The vacuum level reached using the turbo-pump alone is higher than expected for a turbo-pump speed of 1400L/hr which should be ~ 5x10^{-7} mbar. With cryo-pumping, a pressure of < 10^{-8} mbar should be achievable. Possible causes are:

- **High outgassing rate**.
  To ensure that the cryostat and the FPU are light tight, it is necessary to seal up edges that could be a stray light path. Also, the cryostat vessels are wrapped in several layers of aluminised mylar to reduce the heat loads to optimise the hold-times. Both are inconsistent with good vacuum practice where it is best to ensure a good venting path and minimise surfaces. The combined effect is a high outgassing rate which results in a poor ultimate vacuum.

  The vacuum could be improved by heating the FPU and 10K shield to ~50ºC during the initial pump-down although care has to be taken as many of the materials used in the cryostat are not suited for use above 50ºC.

- **Air leak in vacuum vessel.**
  Data from a mass spectrometer attached to the pump-port have shown the presence of air while cryo-pumping. This is a strong indication of an air leak during cold operations. Investigations have found air leaks around the HDPE window, the cryoharness vacuum feedthroughs and an unused drop-plate on the rear side of the cryostat. Since the PFM-2 test campaign the O-ring seals on the HDPE window and drop plate, and removal of some scratches on the harness feedthroughs.

A further air leak appears when filling the cryostat. The most likely cause is due to rapid contraction of the pipework in the upper vacuum vessel when transferring liquid helium. For PFM-2 a fix was attempted by pouring Stycast around the pipe welds to seal any potential leaks, though this had little effect.

- **Helium leak**.
  The detector temperatures derived from load curves, suggest that there is helium contamination on the 300mK system [SPIRE-RAL-NOT-2548]. This is supported by data from a mass spectrometer which shows a mass-4 peak during cold testing of ~10^{-9} mbar.

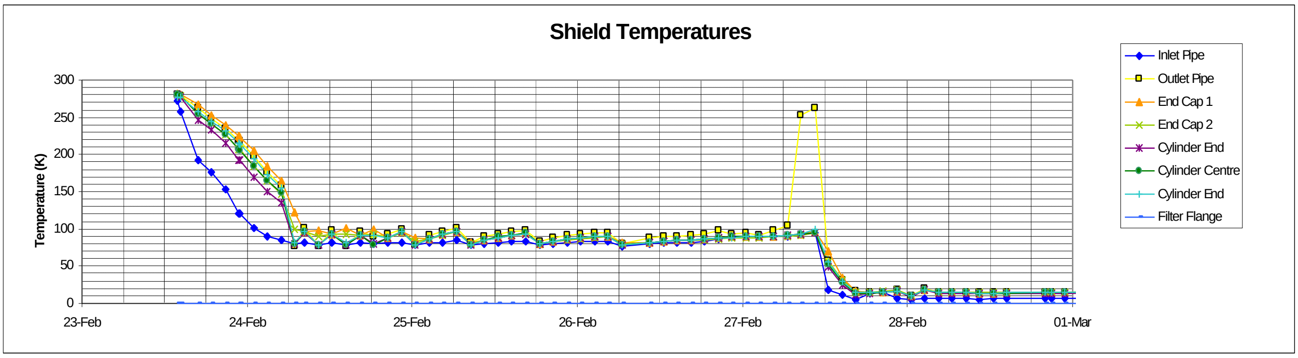
  Attempts to locate the leak at room temperature have not met with success. Monitoring with the mass spectrometer during the PFM-1 cooldown found that the helium leak does not occur until liquid helium is introduced into the L0 vessel. This makes identification and correction of the leak virtually impossible without disassembly of the cryostat.

  To minimise the level of He contamination, the cryostat will be fitted with exfoliated graphite sheets on the 10K shield to act as a sorption pump. Also, it is proposed to allow the FPU and cryostat to warm up to ~80K to decontaminate the system. This should also remove any cryopumped air.

2.1.2 Cooldown

The procedure for cooling down the cryostat and FPU is now well established. After reaching a vacuum of <5×10^{-5}mbar, the helium vessels are pre-cooled using liquid nitrogen until the FPU reaches 80K. This process uses approximately 450 litres of LN2 and takes approximately 5 days to complete.Only when these temperatures are reached is the LN2 carefully removed from the system to avoid the FPU from warming up above 90K. The vessels are then purged with pure helium gas at least 6 times to ensure that there is no nitrogen contamination that could cause a blockage in the system. Cooling from 90K to 4K uses approximately 750 litres of helium assuming that no problems occur during the transfer process.

Typical cool-down plots are shown in Figure 3 and Figure 4.



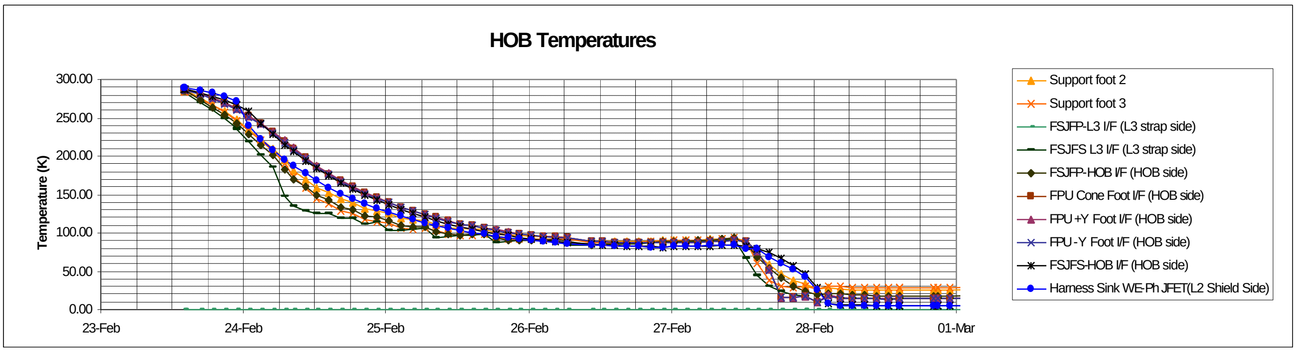


Figure 3. Cryostat shield and HOB simulator temperatures during the cooldown phase of the CQM-2 test campaign.

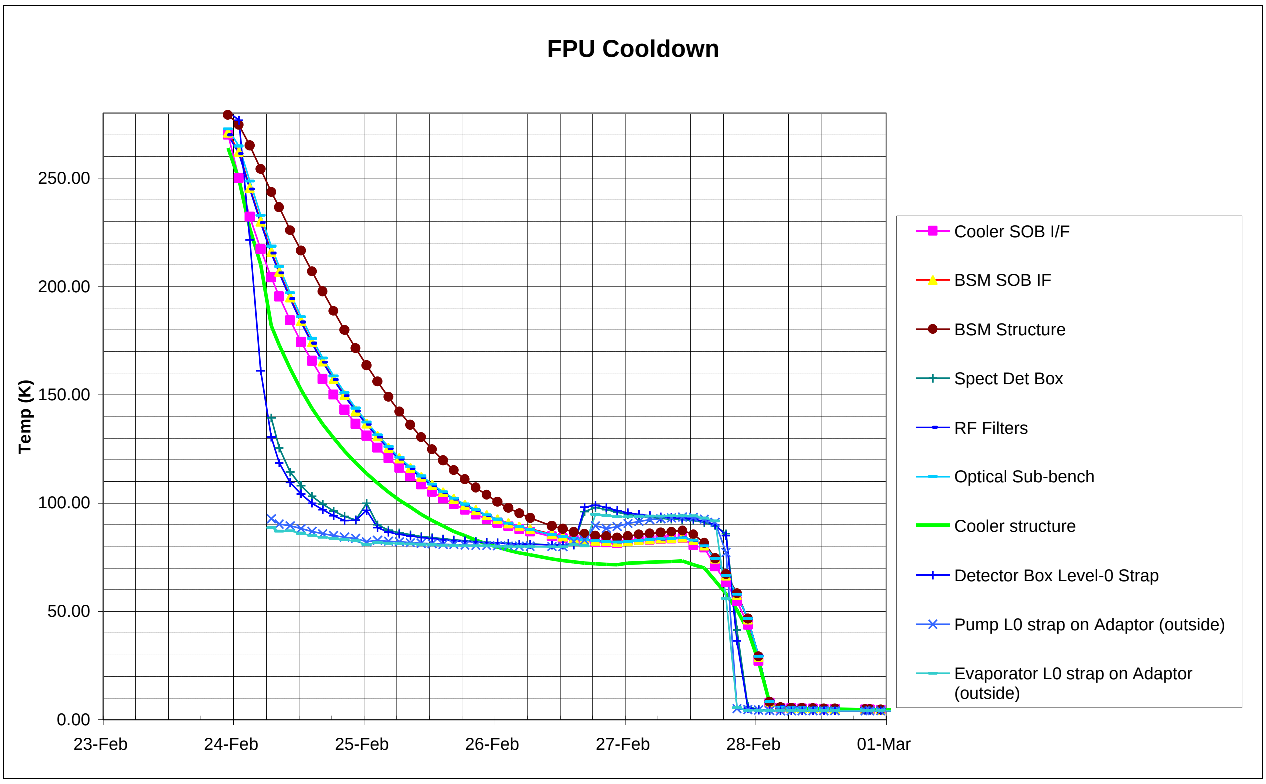


Figure 4. FPU temperatures during the cooldown phase of the CQM-2 test campaign.

For a known heater power P, and heat load ΔP, the volume, v_t of helium remaining in the vessel after a period of t hours is given by

$$v_t = v_0 - \frac{(P + \Delta P)t}{Lr}$$

where the latent heat of vaporization for liquid helium L= 20 J/gm, and the density, r = 0.146g/cm. Measurements with the 4K vessel heater set to 2.7W and 2.1W produced hold time for 100 litres of liquid helium of 27hours and 34hours respectively. In both cases the background heat load on the 4K vessel was approximately 0.3W which was well within the 0.75W allowed for in the cryostat model.

For most test activities the vessel heater is set to 1.65W giving a hold time of approximately 42 hours. Measurements of the helium level vs. time show that the boil off rate is predictable, Figure 5, which makes it possible to schedule refilling around test activities as necessary.

Hold times of the L0 vessel are difficult to predict because there is no direct level monitoring. However, hold times of >48 hours at 1.7K have been demonstrated.

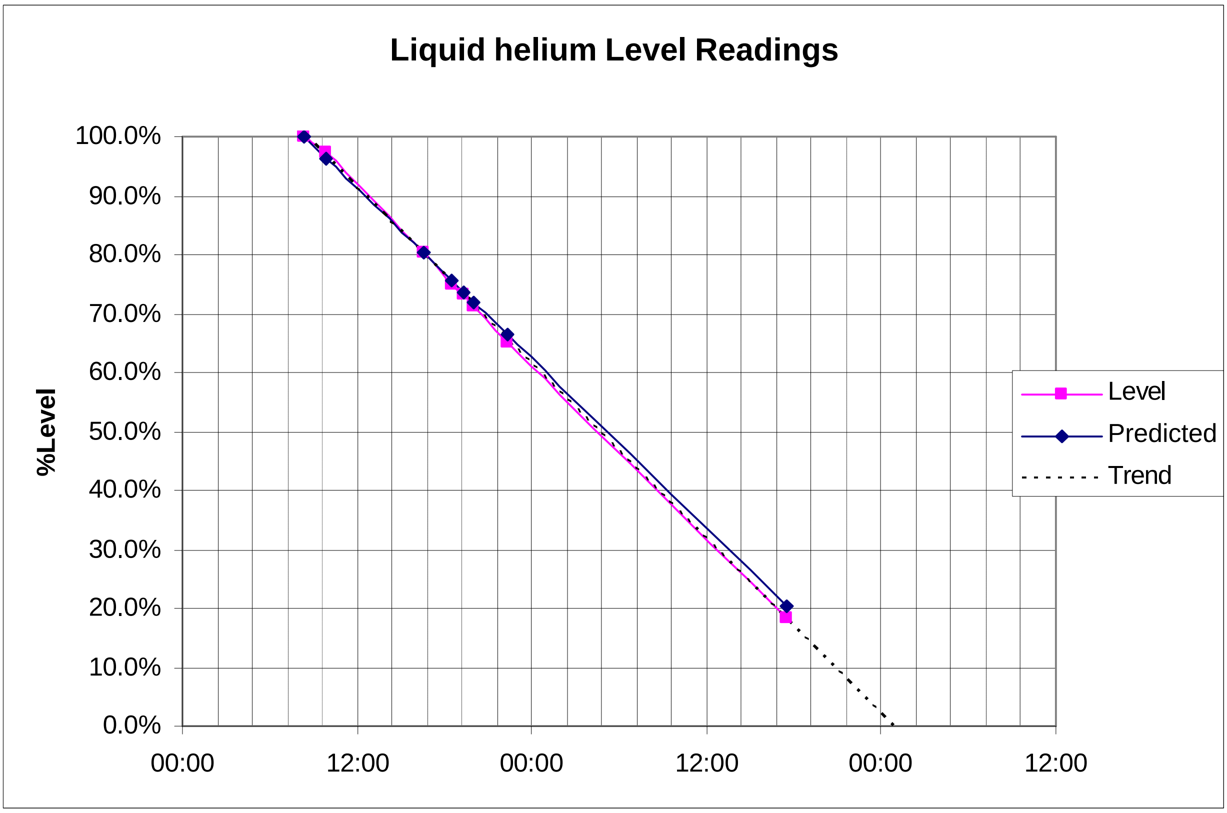


Figure 5. Helium level measured during 2nd CQM test campaign on 24th September 2004

2.1.3 L0 Temperature Control

An Oxford instruments manostat is used to used to control temperatures below 4K. The temperature of the vessel as a function of pressure is in good agreement with the predicted values. Although the temperatures below 2K are higher than expected for a given pressure, it is still possible to achieve and maintain the desired set point of 1.7K. Once the set-point has been reached the manostat is able to maintain the temperature to within a few mK.

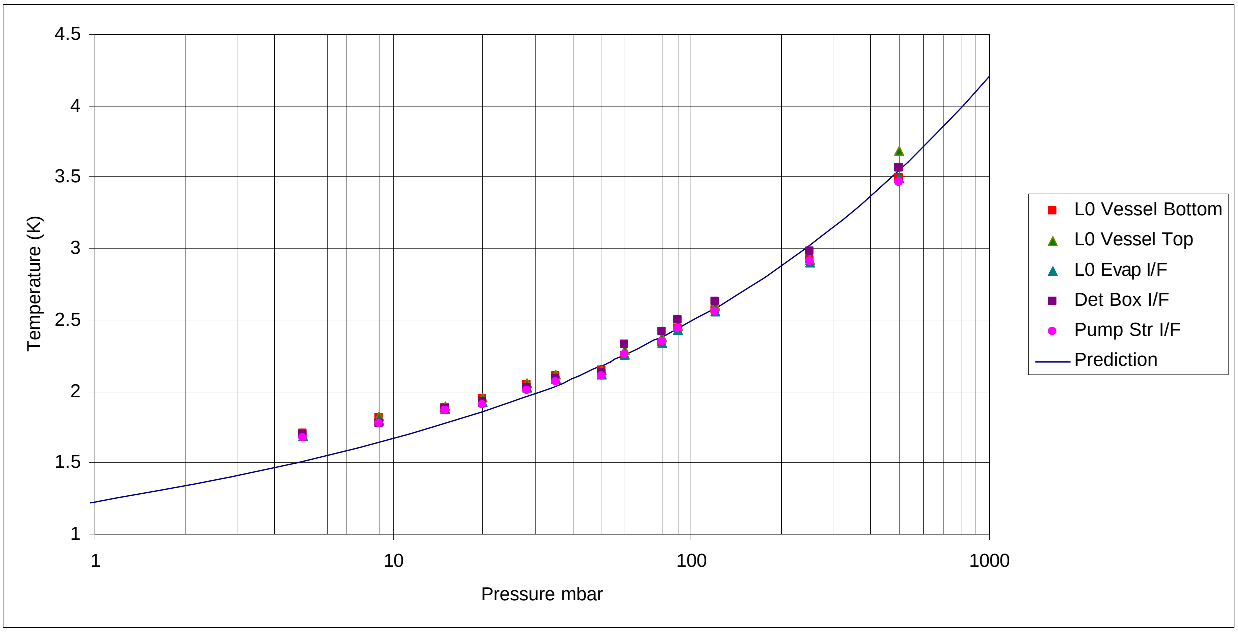
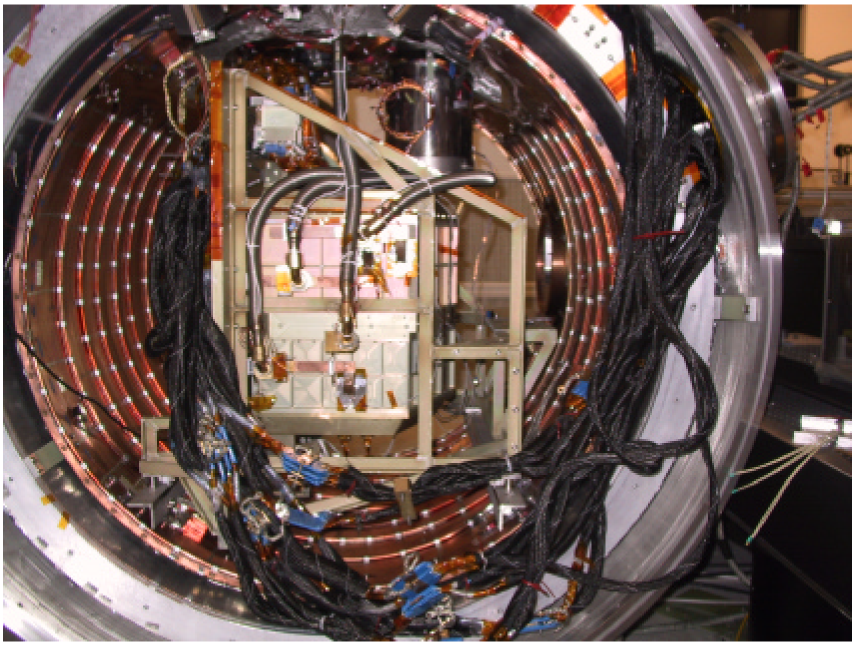


Figure 6. Cryostat L0 temperatures vs. pressure above L0 vessel

2.2 Cryoharness



The SPIRE test cryoharness was built to issue 1.1 of the SPIRE harness definition [ref]. Only three faults were detected that have since been corrected. These were

- Error in manufacture of C1 128 way connector resulting in FPU faraday shield shorting to ground.
- Broken wire in C13 mechanism harness
- P03 connection on C2 was incorrect

The cryoharness was validated against the spacecraft harness specification by ASTRIUM using the IDAS test equipment, demonstrating that the harness wiring conformed to issue 1.2 of the SPIRE harness definition.

In general the harness has performed well and has stood up well to repeat thermal cycling between 300K and 4K.

The main problem faced with the cryoharness has been with electrical shorting from the FPU faraday shield to the cryostat ground. During the manufacture of the harness the external shield was not isolated from the cryostat. However, a significant change to the grounding scheme of the instrument meant that the external shield of the cryoharness had to be isolated. Although insulating netting fitted over the cold section of the harness was used in attempt to isolate the harness shield, it did not prove to be reliable with electrical shorts occurring during integration and after pump-down. This has led to significant delays and frustration in starting the test campaigns. The problem is further complicated when the harness is not routed carefully during integration.

The proposed solution is to remove the netting and wrap the cold harness with Kapton tape. This work has already been carried out and is looking promising, although the taping has affected the harness out gassing rate.

2.3 Cold Blackbody (CBB)

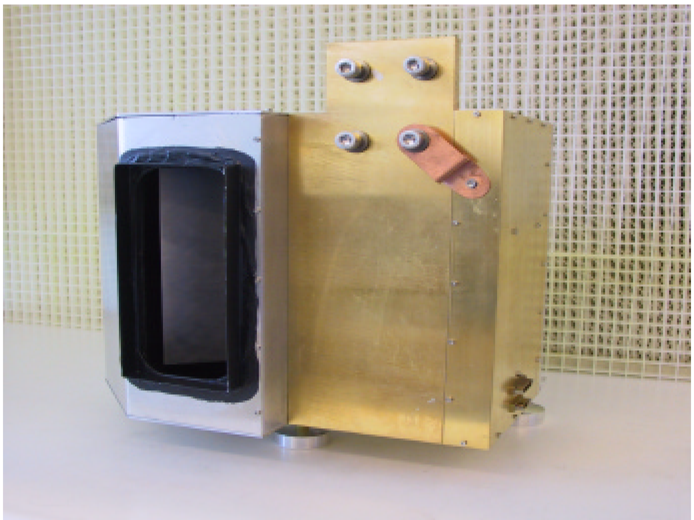


Figure 7. Cold blackbody source

The CBB assembly basically consists of a heated black plate with a flip mirror mechanism. The flip mirror mechanism enables SPIRE to either look out of the cryostat at the rest of the test facility, or at the black plate, without having to warm the cryostat to change the configuration. The main CBB assembly is thermally isolated from the 11-K HOB (Herschel Optical Bench) simulator by three Torlon legs, and cooled by a copper strap to the cryostat 4-K tank.

The CBB generally functions well, despite only reaching a minimum temperature of ~6.5K instead of the design goal of 4.2K. Several design changes have been implemented to attempt to improve the base temperature by reducing the cross section of the Torlon legs, wrapping the main body in MLI, and introducing additional blocking filters on the cryostat to reduce the heat load on the structure. However, none of these modifications have had any real difference on the performance, which leads to the conclusion that we don’t yet have a satisfactory explanation for the anomaly. No further investigations are before the PFM-3 test campaign.

2.4 Control and Monitoring (TFCS)

The TFCS is mainly used to monitor the cryostat and cold blackbody parameters, and to control and monitor the telescope simulator. Several improvements have been made during the CQM and PFM-1 and 2 campaigns and the system is now reasonably stable.

Changes from PFM-2

SW under configuration control – compiled versions only on TFCS machine

Corrections to thermometer names on temperature monitor menu

Fix to ensure clean disconnection from router on detection of network errors.