PRE-FLIGHT CALIBRATION OF THE LWS

T. L. Lim and B. M. Swinyard

Space Science and Technology Department, Rutherford Appleton Laboratory, CLRC, Chilton, Didcot, Oxon OX11 0QX, UK

ABSTRACT

The ground based calibration facility for the LWS was based on a small cryostat that just fitted the instrument and a warm telescope simulator fed with a powerful far infrared laser. This had the advantage of being relatively cheap to build and flexible to operate during ground test campaigns. A disadvantage was found in that it was not possible to fully explore the absolute photometric response of the instrument.

The rationale behind the choice of the test facility design and the lessons learned for future ground test campaigns for cryogenic instruments are discussed, as well as the consequences for the in-orbit calibration of the ISO-LWS.

Key words: ISO – LWS

1. INTRODUCTION

The Long Wavelength Spectrometer (Clegg et al. 1996) was one of two complementary spectrometers on ISO (Kessler et al. 1996) and operated either in high or medium resolution mode in the 44–197μm wavelength range. The LWS used ten detectors (Church et al. 1993), overlapping in wavelength response to cover this range.

The medium resolution ($\Delta\lambda/\lambda \sim$ 200–300) mode consisted of a grating spectrometer which operated in first order for the five longest wavelength (LW) detectors and in second order for the five shortest wavelength (SW) detectors. A Ge:Be detector was used for the 45–50μm range, five unstressed Ge:Ga detectors for the 50–110μm range and four stressed Ge:Ga detectors for the 110–200μm range. The detector spectral ranges were determined by the scanning range of the grating and individual filtering on each detector. The grating was nominally scanned over a range of 3.5°, however the instrument design allowed for the grating to be scanned over an extended range to allow sufficient spectral coverage to cover for a failed detector.

For the high resolution mode ($\Delta\lambda/\lambda \sim$ 10,000), one of two Fabry-Pérot interferometers was placed in the beam, the short wavelength Fabry-Pérot (FPS) was optimised for the 44–90μm range and the long wavelength Fabry Perot (FPL) for the 90–200μm range.

The LWS was extensively tested prior to launch both at subsystem level and system level. Section 2 describes the test facility that was used for system level tests and the test programme details are given in Section 3. The performance testing is described in Section 3.1 and the operations testing is described in Section 3.2. The detailed calibration is given in Section 3.3 and the lessons learned from the in-flight operation and performance of LWS, both in terms of what was done correctly and what was done wrongly, are summarised.

2. FACILITY DESIGN OVERVIEW

Figure 1 shows a schematic of the ground test setup for the instrument level tests. The ground testing of the LWS was conducted using a wet cryostat housing the Focal Plane Unit (FPU), and the instrument was fed by a warm telescope simulator (Emery et al. 1993). The cooling for the instrument was provided by liquid helium pumped to a little below atmospheric pressure and the instrument mounting surface was maintained at $\sim$3.5 K with copper straps. The four stressed detectors were maintained at $\sim$1.7 K with a direct connection to a separate tank. This tank was pumped to 1.7K and was filled with liquid helium from the main vessel through a valve operated from outside the cryostat. The pumping for both tanks was pressure controlled using manostats to maintain stable temperatures. The six unstressed detectors had a temperature of $\sim$3 K maintained by heaters placed in the detector assembly.

The time needed to cool down and warm up the cryostat was a critical design consideration. The cryostat volume was designed to be just large enough for the LWS. This minimised out-gassing surfaces and hence the time needed to evacuate the cryostat prior to cooling could be kept as short as possible allowing individual test programmes which require a few days to complete within a week. During this time, and for longer tests, the system required continuous control and monitoring and this was mainly automatic.

The wavelength calibration was determined by the use of a far-infrared (FIR) laser, with a 10.6μm CO_2 laser used as a pumping laser. The FIR laser could be supplied with various gases giving about eight lines across the LWS wavelength region. The laser beam was passed through a warm telescope simulator which produced a beam of the correct focal length at the LWS entrance aperture (Gray and Emery 1989). Although the FIR laser was required to pass through the entrance aperture of the cryostat, the unattenuated background power from the laboratory would have been sufficient to saturate the detectors and disrupt the thermal balance of the cryostat. To maintain a reasonable background power, a large amount of cooled neutral density filtering was placed in the beam. This gave an

Proceedings of the Conference "The Calibration Legacy of the ISO Mission", VilSpa, Spain, February 2001
ESA SP-481, 2003, eds. L. Metcalfe, A. Salama, S. B. Peschke & M. F. Kessler

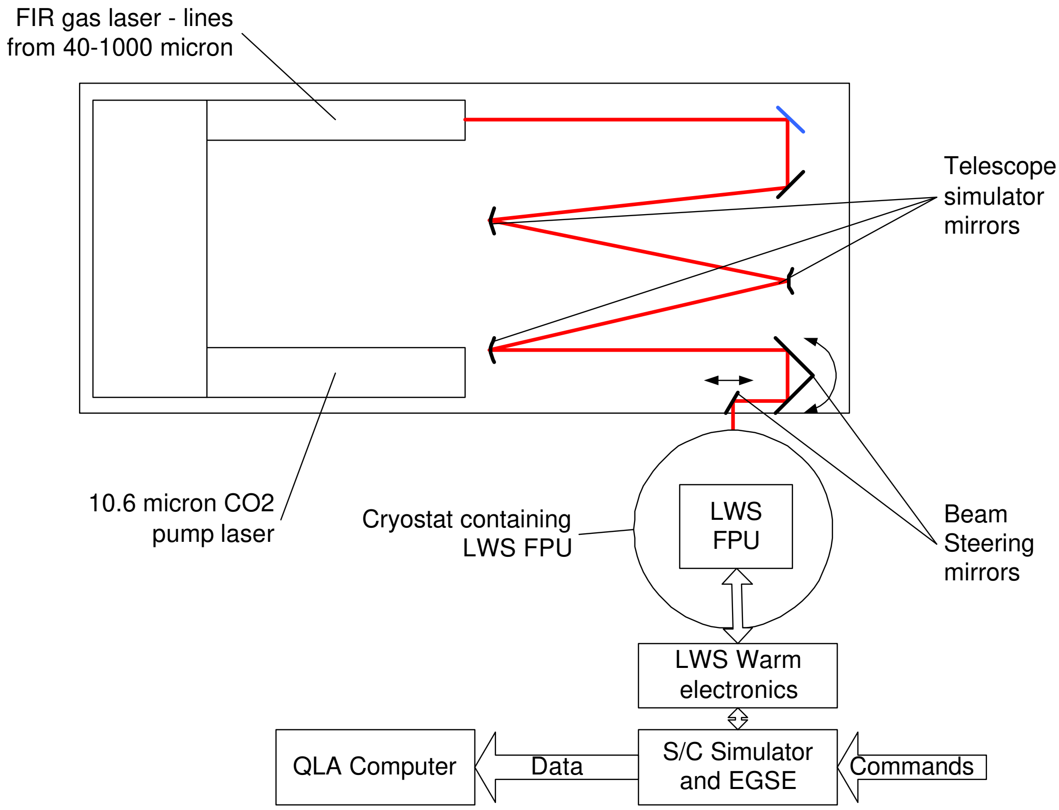

Figure 1. LWS system-level test setup.

attenuation of about 10^5 on the background but was still sufficiently low to allow penetration by the laser. The laser was not an absolute photometric standard and for photometric calibration no source was bright enough to penetrate the neutral density filters, so a black body source was placed inside the cryostat.

The infrared laser system was also used for checking the position of the infrared focus with respect to the reference mounting surfaces. No attempt was made to check the internal alignment of the instrument or the direction of the optical axis, as these were considered to be set accurately during assembly. These checks were made with an alignment model of LWS placed into the cryostat and cooled without the neutral density filtering being installed, so the focus position could be observed through the cryostat window. The adjustment needed to move the beam from the optical reference surface and on to this defined focus was then calibrated. The LWS was then re-mounted with the neutral density filtering in place, and the position and alignment of the infrared beam was set to match the optical reference surface. The calibrated adjustments were then applied to bring the beam down into the LWS focus. The grating mode set to measure the line strength was then used to produce a contour map by scanning the beam horizontally and vertically. This agreed well with the optical position.

The design of the test facility was such that the laser, telescope simulator, cryostat, warm electronics, on-board computer and thermal vacuum control system were placed in the clean room. The FPU was connected through the warm electronics and on-board computer to the Electronics Ground Support Equipment (EGSE) and telescope simulator situated in an adjacent operations room. The EGSE had a direct link to the Quick Look Analysis (QLA) computer. Commands were sent from the EGSE to the on-board computer which set up the analogue electronics to give the control signals for the LWS and the settings for the data electronics. The test signals were provided either with the laser or a black body source placed inside the cryostat. The laser and optics were operated manually.

3. TEST PROGRAMME OVERVIEW

The test programme was designed to build up the instrument understanding from sub-system level to integration and by the end of testing, the optimum operation, basic calibration and data processing architecture had been setup. The main stages of testing were:

- instrument integration and functional test of the instrument interfaces
- functional characterisation of the instrument before and after vibration testing
- performance characterisation of the instrument under operating conditions
- wavelength and photometric calibration of the instrument in all modes
- definition of the in-flight operations
- production of the instrument database.

3.1. Performance testing

Most time during performance testing was spent on the characterisation of the detectors. Through this, faults in the design were found and changes were made between the original 'flight model' and the actually flown 'prime model'. The first model delivered had been intended to be the 'flight model' however after the faults were found changes in design were made to what had originally been scoped as the 'flight spare'. One of the principal problems discovered by performance testing was that the unstressed Ge detectors, originally expected to be operated at 1.7K, did not work well at that temperature, as they exhibited excessive responsivity and spontaneous spiking. The focal plane design was then changed to have a heater for the the unstressed detectors so they could be operated at 3K. The stressed detectors continued to be operated at 1.7K. The redesign also included a straylight baffle added to detector cold pre-amps as the detectors were picking up flux from the wires on the JFETS.

Optimum performance parameters for the detectors were set after extensive testing. Wavelength calibration for the grating was set up very accurately. The alignment of the instrument was verified in the far-infrared. Fabry-Pérot performance was tested and found not to agree with predictions, mainly in terms of transmission, which was found to be below expectations. The two Fabry-Pérots were accurately wavelength calibrated and the parallelism was set up. End-to-end photometric performance was tested using a black body close to the LWS entrance. This filled the beam and appeared as an extended source. The relative response of the instrument with wavelength was characterised using the same source (see Section 3.3).

3.2. Operations testing

The main aim of operations testing was to optimally set up the instrument observing modes in order to use the instrument in the best way for its scientific goals. During operations testing many changes were made to the instrument configuration and operation in order to make the instrument function correctly and optimally. These changes required many patches to be made to the on-board software. The method of operating the instrument and basic calibration scheme was set up for observers using the instrument. Four types of observation (AOTs) were defined for users and these were then optimised further.

Wavelength (μm)	Detector ID	Grating Res.	FPL Res.	FPS Res.
57.000	SW2	205	-	8700
57.000	SW3	174	-	-
70.511	SW3	231	-	7300
70.511	SW4	207	-	-
96.522	LW1	162	9800	7800
118.834	LW1	209	9500	6800
118.834	LW2	180	-	-
163.033	LW4	244	8800	-
163.033	LW5	236	-	-

Table 1. LWS resolving power measured from laser lines in the ground test facility.

The knowledge gained from the ground-based functional tests, calibration and the set up of the AOTs was used to define the offline processing architecture and algorithms. The Real Time Assessment (RTA) and the QLA systems were defined, implemented and fully tested during ground testing at instrument and system level. The in-flight commissioning phase tests were also fully checked out on the flight spare.

3.3. Calibration

3.3.1. Wavelength calibration

The calibration involved setting up the laser to give, in turn, a number of lines covering the wavelength range of the LWS and measuring the detector response when the spectrometer was scanned over each line. The FIR laser was filled with the appropriate gas, then the CO_2 laser and FIR laser were adjusted to give a specific laser line. Further adjustments were made whilst looking at the laser monitor to make the signal as stable as possible. The value of the encoder setting corresponding to the centre of the response was noted and tabulated against the known wavelength of each line. The calibration of the grating was given by a best fit through the points. For the Fabry-Pérots the wavelength does not relate to a unique setting since it also depends on the order of interference, here a fit was made to the command value plotted against the effective separation between the etalons (d) which is given by the order number (m) multiplied by half the wavelength (λ) i.e. $d = m\lambda/2$.

3.3.2. Resolving power

Once the wavelength calibration had been established the resolving power of the two observing modes could be determined. For the grating, the resolving power is taken as the line centroid wavelength divided by the Full Width Half Maximum (FWHM) of the grating response function i.e. $\lambda/\Delta\lambda_{FWHM}$. The resolving power of the Fabry-Pérot is given as the free spectral range ($\Delta\omega$) multiplied by the order (m) divided by the FWHM of the order in question i.e. $m\Delta\omega/\Delta\lambda_{FWHM}$. Table 1 3.2 gives the resolving powers determined during pre-flight testing, reported by Emery et al. (1993).

Detector ID	Wavelength (μm)	Signal ($e.s^{-1}$)	Noise ($e.s^{-1}$)	Responsivity LWS (A/W)	Responsivity Detector (A/W)	Instrument Transmission (%)	Sensitivity NEP_{LWS} ($W/H_z^{-1/2}$)
SW1	46.1	1199	23	0.066	0.38	17	5.6E-17
SW2	56.0	592	51	0.047	0.27	17	1.7E-16
SW3	66.0	1108	28	0.100	0.70	14	4.5E-17
SW4	75.6	667	26	0.096	0.57	17	4.3E-17
SW5	84.7	940	21	0.086	0.90	10	3.9E-17
LW1	102.1	1731	37	0.223	-*	-	2.7E-17
LW2	122.0	714	32	0.401	2.20	19	1.3E-17
LW3	141.7	3253	45	1.280	-*	-	5.6E-18
LW4	160.5	2596	48	0.702	4.10	17	1.1E-17
LW5	178.1	2065	23	0.628	7.90	8	5.9E-18

*Table 2. Detector parameters from instrument-level tests. *These detectors had no subsystem value of responsivity available.*

3.3.3. Detector characterisation

Church et al. (1993) give the details of the detector sub-system tests in which the detectors and filtering were extensively characterised. The detector performance within the instrument was also characterised in the test facility, mainly using a cryogenic black body. The laser system was deemed unsuitable for this due to difficulty in measuring the transmission of the elements in the beam path, namely the vacuum window, the crystal quartz filter and the neutral density filter, at the specific wavelength of the laser line. The effective area and solid angle of the black body were given by the optical modelling of the instrument.

The relative response of each detector was found by measuring the response to a very low signal from the black body as a function of wavelength. This was repeated at each detector bias. The low signal allowed an accurate response curve to be measured but the absolute calibration of the signal was uncertain as the measurement did not correspond to the Rayleigh-Jeans part of the spectrum. The black body was variable in temperature, hence by increasing the temperature of the black body, the detectors could be placed on the Rayleigh-Jeans part of the spectrum. However this caused the signal to be so strong that the detectors became saturated. Therefore, for this test the detector bias was reduced below optimum. The calibration was then scaled using the relative response at different bias curves. Table 2 gives the instrument sensitivity parameters reported by Emery et al. (1993) from the instrument level tests. The values obtained compared well with the instrument specification.

During ground-testing few glitches were observed, however the detectors were known to exhibit transient behaviour. Hence the optimal set up from ground-testing was slow scanning at three ramps per step. Long integrations were ideal as this reduced the noise. The planned ramp length for in-flight operation was 2 s. In-flight, the high glitch rate and increased responsivity of the detectors led to a change in the way the detectors were operated. The changes made to the operation of the detectors and the updated detector parameters are given in Leeks et al. (2003).

4. LESSONS LEARNED

4.1. What we did right

The instrument integration and functional testing was, in the end, routine, and what we learnt at instrument level translated directly to the satellite checkout and the in-flight commissioning. The basic performance characterisation of the LWS was successful and the understanding gained provided a good basis for the in-flight performance verification phase. The AOTs also, in the end, worked well in-flight and the experience of extensively learning how to operate the instrument in operations testing had a significant impact on this. The basic offline processing architecture was set up correctly on the back of ground test experience and has been almost unchanged since. Using the same RTA/QLA system at all integration levels made in-flight commissioning operationally straightforward and the use and early development of the real time systems at instrument level made sure that it was ready for launch.

4.2. What we did wrong

We missed a vital design flaw in the optical design of the LWS which was only picked up in-flight when fringes were observed on the spectra and the beam characterisation was giving unexpected results. This was because we used a monochromatic source at the input to the telescope simulator and therefore could only reference the black body to itself. The small cryostat saved a lot of money, however the filtering scheme possibly could have been better, allowing for a external black body to be used for the calibration. The thermal environment in the LWS cryostat was very different to ISO i.e. liquid versus gas cooled. We had to set up operations in-flight differently because of this, in particular the optimal way to operate the internal calibrators was very different in-flight to on the ground. The radiation environment in-flight invalidated all our ground testing for the detectors, which meant that the detectors had to be almost completely re-calibrated using in-flight data, however the extensive experience of setting up the detectors allowed the correct settings to be found and tested quickly in-flight.

REFERENCES

Church, S.E., Griffin, M.J., Price, M.C. et al., 1993, SPIE, 1946, 116
Clegg, P.E., Ade, P.A.R., Armand, C., 1996, A&A, 315, L38
Emery, R.J., King, K.J., Swinyard, B.M. et al., 1993, SPIE, 1946, 272
Gray, P.F. & Emery, R.J., 1989, SPIE, 1191, 4
Kessler, M.F., Steinz, J.A., Anderegg, M.E., 1996, 315, L27
Leeks, S.J., Swinyard, B.M., Lim, T.L. et al., 2003, this volume