SPIRE Science Verification Review

SMEC and Spectrometer Performance

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1.Introduction and scope

This document compares the performance of the SPIRE imaging spectrometer during the PFM4 and PFM5 ground-based test campaigns against the scientific requirements. Special emphasis is given to the spectrometer mechanism.

2.List of requirements that the test programme was designed to evaluate

The SPIRE spectrometer requirements (ref. 1) that were evaluated during the PFM4 and PFM5 test campaigns are given in Table 1 below. Also indicated in the table is whether the information regarding the requirement has been updated since SVR2.

Requirement Number	Description	Requirement	Update since SVR-2
IRD-SPEC-R01	Wavelength Range [μm]	SSW: 200-300 SLW: 300-670	Yes
IRD-SPEC-R02	Maximum Resolution [cm^{-1}]	Req: 0.4 Goal: 0.04, resolution element 0.0483, FWHM	Yes
IRD-SPEC-R03	Minimum Resolution [cm^{-1}]	Req: 1 Goal: 2	No
IRD-SPEC-R11	Vignetting	<10% uniformity at a resolution of 0.4cm^{-1}	Yes
IRD-SPEC-R14	Fringe Contrast	>80% at a resolution 0.4cm^{-1}	Yes
IRD-OPTS-R07	Balancing of ports	Beamsplitters shall have $2RT=R^2+T^2$ to within 90% over the band	No
IRD-OPTS-R09	In-band straylight	<5% for each band	Yes
IRD-OPTS-R10	Off-axis resolution	FWHM < 110% of nominal resolution	Yes
IRD-SMEC-R01	Linear Travel	Req: 14cm total OPD	Yes
IRD-SMEC-R02	Minimum movement sampling interval	5μm SSW 7.5μm SLW	No
IRD-SMEC-R03	Sampling step control	Interval variable between 5 and 25μm	Yes
IRD-SMEC-R04	Scan length	Able to start a scan from either side of ZPD	Yes
IRD-SMEC-R05	Dead-time	<10% at resolution of 0.4cm^{-1}	Yes
IRD-SMEC-R06	Mirror velocity	Req: 0.1cm/s MPD Goal: 0.2cm/s MPD	Yes
IRD-SMEC-R07	Velocity control	Selectable from 0 to 0.1cm/s	Yes
IRD-SMEC-R08	Velocity stability	<10μm/s RMS over the full range of movement	Yes
IRD-SMEC-R09	Position measurement	0.1μm within +/- 0.32cm of ZPD, 0.3μm elsewhere	Yes

Table 1: SPIRE Spectrometer Requirements (ref. 1)

3.Test results and conclusions

3.1.1 Wavelength Range (IRD-SPEC-R01)

The edges of the SPIRE spectrometer wavebands (SLW and SSW) are defined as the points where the spectral intensity is one half of its average single-mode in-band value. In order to focus on the response of the detectors themselves, the contributions to the measured spectrum from the input sources (CBB and

SCAL) were removed (see ref. 5). The measured edges of the spectrometer wavebands shown in Table 2 are the average (± 1 σ) for the active pixels in each array.

	SLW		SSW	
	Cut-on [cm^{-1}]	Cut-off [cm^{-1}]	Cut-on [cm^{-1}]	Cut-off [cm^{-1}]
Requirement	14.64-15.02	33.00-33.67	30.40-31.15	52.08-53.19
PFM3	14.899 ± 0.091	33.525 ± 0.096	31.37 ± 0.17	51.98 ± 0.20
PFM4	14.91 ± 0.10	33.535 ± 0.084	31.30 ± 0.35	52.12 ± 0.37
PFM5	14.98 ± 0.13	33.57 ± 0.11	31.32 ± 0.28	52.24 ± 0.31

Table 2: SPIRE Spectrometer waveband edges

As can be seen from the results presented in Table 2, the waveband edges as measured from PFM4 and PFM5 data showed no significant difference from the band edges defined by the PFM3 data. As such, the conclusions with respect to the band edges are the same as those that followed the PFM3 test campaign. That is, the band edges for the SLW array as well as the high-wavenumber (short-wavelength) SSW band edge meet the specifications within measurement uncertainty. With respect to the SSW low-wavenumber (long-wavelength) edge, while it was found to be marginally outside the specification, its value combined with the high-wavenumber (short-wavelength) edge of the SLW waveband still ensures an overlap of 2cm^{-1} between the two detection bands.

3.1.2 Maximum Resolution (IRD-SPEC-R02), Off-Axis Resolution (IRD-OPTS-R10)

There are many definitions of resolution in the field of spectroscopy. One of the most widely used is the full width at half maximum (FWHM) of the instrumental line shape (ILS) of the spectrometer. This definition is well suited to spectrometers, such as a diffraction grating or a Fabry-Perot interferometer, whose ILSs are not well defined. The Fourier transform spectrometer, in the ideal case, possesses the best ILS of any spectrometer – the well-known sinc function. The sinc function possesses secondary oscillations that decay in amplitude at increasing difference frequencies from the line centre. The resolution of an FTS based upon the FWHM criteria gives a slightly higher value than that obtained if all the information in the extended sinc ILS is used in the subsequent data analysis.

The resolution of the SPIRE spectrometer was determined by way of observations of unresolved line sources. The line source used in the PFM4 tests of the FM SMEC was an infrared laser. Due to time constraints and because the line source can only be focussed on one detector pixel per observation, measurements of the FWHM spectral resolution are only available for limited set of the SLW and SSW pixels.

The PFM4 test results, presented in detail in Table 7 (§8.1), show that the FM SMEC meets the requirement and the goal for the maximum spectral resolution (0.4cm^{-1} and 0.0483cm^{-1} FWHM) within measurement uncertainty. In addition, for the pixels within the unvignetted field of view, the goal that the measured resolution not exceed 110% of the maximum FWHM resolution (0.0531cm^{-1}) has also been achieved within measurement uncertainty (IRD-OPTS-R10).

3.1.3 Minimum Resolution (IRD-SPEC-R03)

The original goal for the minimum spectral resolution of 4cm^{-1} was found to be impractical. Due to the inherent limits on the SLW and SSW bands, a minimum resolution of 2cm^{-1}, while achievable, would result in only 11 in-band points for the SLW array and 12 in-band points for the SSW array. This low number of data points may make it difficult to properly correct for instrumental effects within the wavebands and will lead to difficulty in the interpretation of the measured spectra. For this reason, the minimum resolution of the SPIRE spectrometer during operations will be 1cm^{-1} (see ref. 3).

3.1.4 Vignetting (IRD-SPEC-R11)

Vignetting, the loss of power for off-axis pixels at high optical path differences, was observed in data from each of the PFM test campaigns. At the required resolution of 0.4cm^{-1}, the baseline of the measured interferograms was found to be uniform to within 2%, meeting the requirement of 10% uniformity (see §8.2). At the maximum spectral resolution for the SPIRE spectrometer, uniformity to within 10% was measured on all of the pixels that lie within the unvignetted field of view as well as on most of the pixels that lie outside this field of view (see §8.2 for plots of the measured vignetting for all active channels from the PFM4 test campaign).

3.1.5 Fringe Contrast (IRD-SPEC-R14)

During the PFM4 test campaign, the laboratory infrared laser was used to study fringe contrast. As was the case for the infrared laser during the PFM1 and PFM3 test campaigns, only a subset of the pixels in each spectrometer detector array was directly illuminated with the laser. The results of these tests, given in detail in Table 8 in §8.3, show that, for pixels within the unvignetted field of view, the measured fringe contrast exceeds the predicted value of 87% given in ref. 2.

3.1.6 Balancing of Ports (IRD-OPTS-R07)

Calculations based on the measured beamsplitter transmission and reflection show that for each input port, the beamsplitters divide the output to the two detector arrays equally to within 5% over the range 20—50cm^{-1} and to within 10% at the long wavelength SLW edge (15—20cm^{-1}). In both cases, the results satisfy the 10% requirement.

With respect to overall port transmission, the PFM tests have shown that while the SCAL sub-system is capable of compensating for the emission from the laboratory cold blackbody (CBB) source, the compensation occurs at different temperatures for pixels in the same detector array (see ref. 5). In addition, the range of temperatures over which spectral compensation was achieved was different for the two detector arrays. As a result, it may be necessary to choose a temperature that, while not optimal for any given pixel, is optimal for two detector arrays as a whole.

It should be noted that the compensation studies to date have by necessity involved the CBB and not the actual telescope. As such, the final SCAL settings for the optimal spectral compensation will only be found in flight when the Herschel telescope, the temperature and emissivity of which are still unknown, is the other source of emission.

3.1.7 In-band Straylight (IRD-OPTS-R09)

Throughout the PFM test campaign phase, the major cause of in-band spectral straylight has been attributed to the presence of channel fringes. It has been shown that the replacement of the field lenses prior to the PFM3 test campaign led to a reduction in the intensity of the channel fringes, in particular for off-axis pixels (see §8.5). Further study of the PFM4 data has shown that for all active pixels with the exception of pixel SLWC3, the ratio of the in-band channel fringe spectral power to that of the source is less than 4%, meeting the <5% requirement. In the case of pixel SLWC3, the central pixel of the SLW array, the ratio was found to be 6%, slightly exceeding the <5% straylight requirement.

3.1.8 Linear Travel (IRD-SMEC-R01)

The range of mechanical motion for the FM SMEC as measured from the PFM4 and PFM5 test campaigns was 39.5mm. Taking into account the factor of four conversion between mechanical to optical path travel due to the Mach-Zehnder design of the SPIRE FTS gives a total optical path difference of 15.8cm, exceeding the requirement of 14cm OPD. The maximum single-sided optical path travel, factoring in the mean position of zero path difference as measured during the PFM4 test campaign (7.86mm MPD) was found to be 12.656cm.

3.1.9 Minimum movement sampling interval (IRD-SMEC-R02)

The servo system of the spectrometer mechanism is designed to provide any sampling interval requested. The sampling interval results from a combination of the spectrometer mechanism speed and of the sampling rate of the detectors. The current design is for a detector sampling rate of ~80Hz, for a speed of 0.1cm/s the sampling interval is 12.5μm and is 1.25μm for a speed of 0.01cm/s, which meets the requirement for both detector bands.

3.1.10 Sampling step control (IRD-SMEC-R03)

In the nominal continuous scan operating mode of the spectrometer the control of the SMEC is maintained on the speed and not the size of the sampling step. The SMEC servo system is, however, designed to provide any step value that is an integer number of 1μm. During the PFM4 and PFM5 test campaigns the step-and-integrate mode was tested and the 1-σ position errors were found to be 0.533μm for each step. While this value exceeds the specification, it was found that this position error did not have a negative impact on the detector noise (see §8.7).

3.1.11 Scan length (IRD-SMEC-R04)

While the functionality defined by this requirement has not been formally tested during any of the PFM test campaigns, there were occasions during the PFM4 test campaign wherein the mechanism began a scan from the position of maximum optical path difference. These instances demonstrate the SMEC's ability to start a scan on either side of zero path difference.

3.1.12 Dead-time (IRD-SMEC-R05)

During the PFM4 test campaign, three different SMEC PID control settings were examined. The dead-time, defined as the time during which the SMEC is accelerating at the start of each scan was measured for each PID control setting (see §8.5 for a more detailed discussion of the SMEC dead-time).

In order to compute the proportion of the total scan time that is consumed by the dead-time, it is first necessary to compute the total scan time for a given resolution. The *total* scan length required, L, is inversely proportional to the resolution. For the required resolution of 0.4cm^{-1}, an overall scan length of 7.56mm is required. The overall scan time at the nominal scan speed of 0.05cm/s is therefore equal to 15s.

The results presented in the Table 3 below confirm that, at the nominal SMEC scan speed of 0.05cm/s, the performance of the spectrometer mechanism satisfied the requirement of the dead-time being <10% of the total scan time, regardless of the SMEC PID control settings.

SMEC PID Settings	Dead-Time [s]	Dead-time [% of scan time for R=0.4cm^{-1}]
Kp=1000, Ki=2000, Kd=10000	0.427 +/- 0.030	2.8
Kp=1000, Ki=2000, Kd=2500	0.478 +/- 0.046	3.2
Kp=2000, Ki=1000, Kd=700	0.290 +/- 0.054	1.9

Table 3: Dead-time for the SMEC PID settings studied during the PFM4 test campaign

The dead-time was also measured for other SMEC scan speeds during the PFM4 test campaign (see Table 4). These results show that the dead-time is independent of the scanning speed and that the dead-time requirement is met even for non-standard SMEC scan speeds. In addition, the tests from which these results were derived demonstrate that the SMEC has met the requirements for mirror velocity and velocity control, IRD-SMEC-R06 and IRD-SMEC-R07 respectively.

SMEC PID Settings	Speed, Mechanical Path Difference [cm/s]	Dead-time [s]	Dead-time [% of scan time for R=0.4cm^{-1}]
Kp=1000, Ki=2000, Kd=10000	0.10	0.462	6.2
Kp=2000, Ki=1000, Kd=700	0.01	0.290	0.04
Kp=2000, Ki=1000, Kd=700	0.03	0.463	1.9
Kp=2000, Ki=1000, Kd=700	0.10	0.265	3.5

Table 4: Dead-time for SMEC scan speeds and PID settings studied during the PFM4 test campaign

3.1.13 Spectrometer mirror velocity control and stability

This section covers two related requirements:

- Velocity stability (IRD-SMEC-R08)
- Position measurement (IRD-SMEC-R09)

As mentioned in §3.1.12, over the course of the PFM4 test campaign, the spectrometer mechanism was operated at three different PID control settings. At each of the PID control settings, the speed and position jitter was measured the results of which are shown, for the nominal SMEC scan speed of 0.05cm/s MPD, in Table 5. As the results presented in Table 5 show, the SMEC meets the speed and position stability requirements for two of the three SMEC PID control settings studied during the PFM4 test campaign.

PID Settings	Unfiltered		Filtered	
	Speed Jitter, RMS [µm/s]	Position Jitter, RMS [µm]	Speed Jitter, RMS [µm/s]	Position Jitter, RMS [µm]
Kp=1000, Ki=2000, Kd=10000	360	1.00	5.5	0.15
Kp=1000, Ki=2000, Kd=2500	30	0.58	6.4	0.15
Kp=2000, Ki=1000, Kd=700	50	0.85	40	0.62

Table 5: Speed and position stability for the SMEC PID settings studied during the PFM4 test campaign

Further study of the effect of SMEC speed and position jitter was undertaken (see §8.7). The purpose of this additional analysis was to investigate the effect that SMEC speed and position jitter has on the spectral signal-to-noise ratio. This study revealed that, even though there is a large difference in the SMEC speed and position jitter for the various PID control settings, the measured in-band signal-to-noise ratio did not differ significantly between these observations.

3.2 List of tests carried out

The following is a brief summary of the spectrometer related tests that were performed during the PFM test campaigns:

- Low, Medium, and High resolution scans with various CBB and SCAL settings as well as with the room/laser/photomixer as the primary source.
- Medium resolution compensation tests were been performed whereby for a given CBB setting, the temperatures of SCAL2 and SCAL4 were varied in turn so as to determine the settings that result maximum compensation of the interferogram signal in the ZPD region.
- Tests of the SOF1 and SOF2 AOTs.
- Tests of the Step-and-integrate mode of the SMEC.

Please refer to §5 and ref. 4 for a list of tests for a list of spectrometer-related tests that are recommended for the PV phase.

4. Open issues and anomalies

Microphonics: During PFM4 some test observations were performed with the SPIRE spectrometer using a microphonics vibration kit. While these observations provided an indication of the behaviour of the SPIRE spectrometer in a noisy environment, the actual response of the SPIRE spectrometer will only be known during flight.

Straylight: The in-band straylight contamination due to the channel fringes has been characterized and quantified for the SPIRE spectrometer (§3.1.7). There is, however, still some uncertainty as to level of straylight contamination during flight. Since the actual straylight environment will only be known from tests performed during the PV phase, further analysis of this phenomenon will be required at that time.

5. Recommendations for further data analysis and tests

The groups at LAM and the Lethbridge have been in consultation and have derived a list of tests for the PV phase. The goals of these proposed tests are to provide the calibration information for the SPIRE spectrometer required for in-flight operations. The following is a brief description of the proposed tests:

At 5K–10K intervals during telescope cool-down or once per week and while the telescope points in a stable manner to a dark region in the sky, the following tests are proposed:

- At each telescope temperature, choose three SCAL settings that avoid clipping the interferograms. The exact temperature settings per telescope temperature will be provided based on models and/or prior experience.
- As the SCAL elements are settling to their commanded values, command the SMEC to perform a set of medium-resolution scans.
- Once SCAL has reached the desired temperature, take a set of full resolution scans. These scans should encompass the full length of the mirror stage, i.e. stretching out farther into the short double-sided wing than the currently defined high-resolution scan.

While the telescope points at an extended region of the sky with known line content:
- Perform a set of high resolution scans.

Some time during the PV phase, the following tests are proposed:
- System-wide tests of the Spectrometer AOTs.
- A set of medium resolution scans with the SMEC speed set to half and twice its default value (0.025cm/s and 0.1cm/s, respectively).

6. Conclusions

A summary of the performance of the SPIRE spectrometer mechanism with respect to its requirements is given in Table 6 below. As shown in Table 6 and as demonstrated in §3 and §8, the SPIRE spectrometer meets or exceeds its requirements for all but one aspect of one of those requirements studied in this report.

Requirement Number	Description	Requirement	Status
IRD-SPEC-R01	Wavelength Range	SSW:200-300μm, 33.3-50cm^{-1} SLW:300-670μm, 14.9-33.3cm^{-1}	Cut-on edge achieved within uncertainty. 2cm^{-1} overlap still exists between bands. Achieved
IRD-SPEC-R02	Maximum Resolution [cm^{-1}]	Req: 0.4 Goal: 0.04, resolution element 0.0483, FWHM	Achieved Achieved
IRD-SPEC-R03	Minimum Resolution [cm^{-1}]	Req: 1 Goal: 2	Achieved
IRD-SPEC-R11	Vignetting	<10% uniformity at a resolution of 0.4cm^{-1}	Achieved
IRD-SPEC-R14	Fringe Contrast	>80% at a resolution 0.4cm^{-1}	Achieved
IRD-OPTS-R07	Balancing of ports	Beamsplitters shall have $2RT=R^2+T^2$ to within 90% over the band	Achieved
IRD-OPTS-R09	In-band straylight	<5% for each band	Achieved
IRD-OPTS-R10	Off-axis resolution	FWHM < 110% of nominal resolution	Achieved
IRD-SMEC-R01	Linear Travel	Req: 14cm total OPD	Achieved
IRD-SMEC-R02	Minimum movement sampling interval	5μm SSW 7.5μm SLW	Achieved
IRD-SMEC-R03	Sampling step control	Interval variable between 5 and 25μm	Achieved
IRD-SMEC-R04	Scan length	Able to start a scan from either side of ZPD	Achieved
IRD-SMEC-R05	Dead-time	<10% at resolution of 0.4cm^{-1}	Achieved
IRD-SMEC-R06	Mirror velocity	Req: 0.1cm/s MPD Goal: 0.2cm/s MPD	Achieved
IRD-SMEC-R07	Velocity control	Selectable from 0 to 0.1cm/s	Achieved
IRD-SMEC-R08	Velocity stability	<10μm/s RMS over the full range of movement	Achieved
IRD-SMEC-R09	Position measurement	0.1μm within +/- 0.32cm of ZPD, 0.3μm elsewhere	Achieved

Table 6: SPIRE Spectrometer Requirements Summary

7. References

1. "*SPIRE Instrument Requirements Document*", Swinyard, Bruce, et. al., SPIRE-RAL-PRJ-000034, 14 July 2005, pp. 16, 48, 56
2. "*SPIRE Design Description*", Griffin, Matt, et. al., SPIRE-RAL-PRJ-000620, 15 May 2003, p. 53
3. "*Spectrometer Performance Review*", Naylor, D. A., et. al., Presentation for the SPIRE Consortium Meeting, Caltech, 19-21 July 2005
4. "*Calibration Requirements for the SPIRE Spectrometer*", version 3.0, Davis, Peter and Fulton, Trevor, 12 October 2007
5. "*PFM1/PFM3 Transmission Analysis*", Fulton, Trevor, 10 August 2006

8.Appendix

8.1 Maximum Resolution (IRD-SPEC-R02), Off-Axis Resolution (IRD-OPTS-R10)

The results presented in the following tables are the measured FWHM resolutions for the spectrometer detector pixels in the SLW and SSW arrays that were examined during the PFM4 test campaign. The central pixels of each array, where the maximum resolution was achieved, are shown in blue.

Test Campaign	Pixel	Line Centre [μm]	Line Centre [cm^{-1}]	Measured Resolution FWHM [cm^{-1}]	R (=λ/Δλ)
PFM4	SLWC3	393.7	25.399	0.0492 ± 0.0094	516
PFM4	SLWC3	393.7	25.398	0.0483 ± 0.0035	526
PFM4	SLWC3	393.7	25.397	0.0484 ± 0.0020	524
PFM4	SLWC5	394.4	25.357	0.049 ± 0.012	520
PFM4	SLWD2	394.0	25.379	0.0491 ± 0.0053	516
PFM4	SLWE2	394.5	25.350	0.0503 ± 0.0019	504
PFM4	SLWE2	394.5	25.349	0.0529 ± 0.0033	479

Test Campaign	Pixel	Line Centre [μm]	Line Centre [cm^{-1}]	Measured Resolution FWHM [cm^{-1}]	R (=λ/Δλ)
PFM4	SSWA2	202.6	49.347	0.05500 ± 0.00053	897
PFM4	SSWA2	202.6	49.352	0.0482 ± 0.0014	1024
PFM4	SSWB3	202.5	49.380	0.05094 ± 0.00036	969
PFM4	SSWB3	202.5	49.380	0.04916 ± 0.00015	1004
PFM4	SSWB4	202.6	49.360	0.04905 ± 0.00049	1006
PFM4	SSWC3	202.4	49.416	0.04695 ± 0.00005	1052
PFM4	SSWC3	202.4	49.416	0.05042 ± 0.00078	980
PFM4	SSWC4	202.4	49.404	0.04751 ± 0.00092	1040
PFM4	SSWD3	202.4	49.398	0.04883 ± 0.00051	1012
PFM4	SSWD3	202.4	49.398	0.04680 ± 0.00007	1056
PFM4	SSWD4	202.4	49.412	0.0483 ± 0.0012	1024
PFM4	SSWD4	202.4	49.412	0.0484 ± 0.0012	1016
PFM4	SSWE3	202.4	49.403	0.04877 ± 0.00012	1013
PFM4	SSWE3	202.4	49.404	0.04933 ± 0.00077	1002
PFM4	SSWE6	202.8	49.310	0.0471 ± 0.0052	1048
PFM4	SSWE6	202.8	49.310	0.04962 ± 0.00070	894
PFM4	SSWF3	202.5	49.381	0.04788 ± 0.00027	1031

Table 7: Measured FWHM resolution for the SPIRE Spectrometer pixels tested during the PFM4 test campaign.

8.2 Vignetting (IRD-SPEC-R11)

The level of vignetting for all spectrometer detector pixels as measured during the PFM4 test campaign is shown in the plots of Figure 1. The plots in Figure 1 demonstrate the compliance of the SPIRE spectrometer with the vignetting requirement of 10% uniformity to a resolution of $0.4 cm^{-1}$.

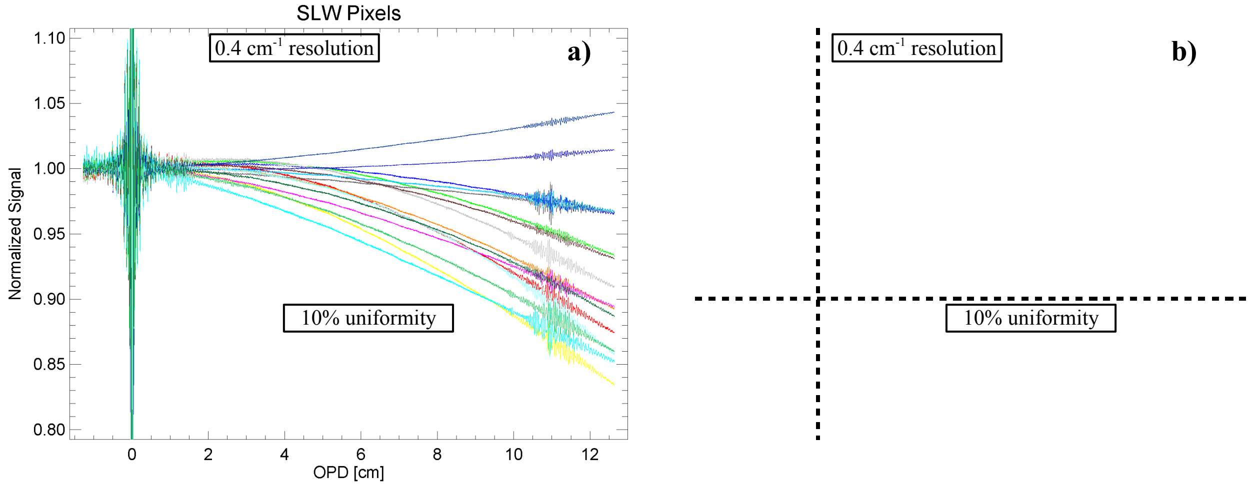

Figure 1: Vignetting for all SPIRE channels as measured during the PFM4 test campaign. a) All active SLW channels; b) All active SSW channels. Also shown on the plots is the threshold for the vignetting requirement.

8.3 Fringe Contrast (IRD-SPEC-R14)

The following tables presents the measured fringe contrast for the SLW and SSW spectrometer detector pixels tested during the PFM4 test campaign.

Test Campaign	Target Pixel	Line Centre [μm]	Line Centre [cm^{-1}]	Fringe Contrast (%) at maximum OPD
PFM4	SLWC3	393.7	25.399	95
PFM4	SLWC3	393.7	25.398	98
PFM4	SLWC3	393.7	25.397	95
PFM4	SLWC5	394.4	25.357	84
PFM4	SLWD2	394.0	25.379	96
PFM4	SLWE2	394.5	25.350	83
PFM4	SLWE2	394.5	25.349	82

Test Campaign	Target Pixel	Line Centre [μm]	Line Centre [cm^{-1}]	Fringe Contrast (%) at maximum OPD
PFM4	SSWA2	202.6	49.347	97
PFM4	SSWA2	202.6	49.352	98
PFM4	SSWB3	202.5	49.380	97
PFM4	SSWB3	202.5	49.380	96
PFM4	SSWB4	202.6	49.360	99
PFM4	SSWD3	202.4	49.398	95
PFM4	SSWD4	202.4	49.412	97
PFM4	SSWD4	202.4	49.412	90
PFM4	SSWE3	202.4	49.403	99
PFM4	SSWE3	202.4	49.404	88
PFM4	SSWF3	202.5	49.381	85

Table 8: Measured Fringe Contrast for the SPIRE Spectrometer pixels tested during the PFM4 test campaign

8.4 Balancing of ports (IRD-OPTS-R07)

The beamsplitter transmissions derived for each of the SPIRE spectrometer input ports are shown Figure 2. The plots demonstrate that, for each input port, the beamsplitters divide the output to the two detector arrays equally to within 5% over the range 20—50cm^{-1} and to within 10% at the long wavelength SLW edge (15—20cm^{-1}). In both cases, the results satisfy the 10% requirement.

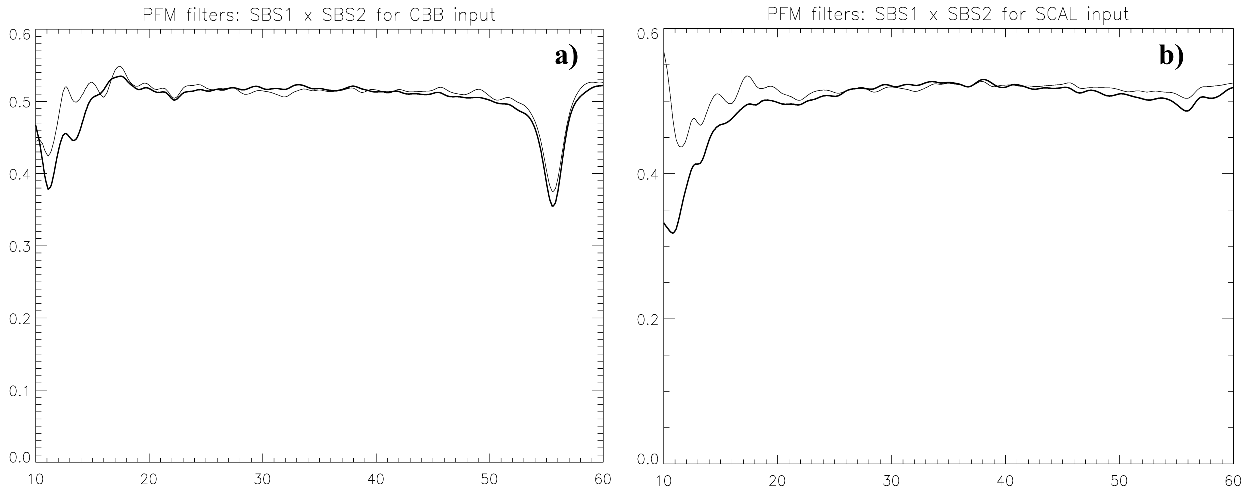

Figure 2: Beamsplitter transmission for the two input ports of the SPIRE spectrometer. a) Telescope input port; b) SCAL input port. In these plots, the thin line corresponds to the SLW detectors and the thick line corresponds to the SSW detectors.

8.5 In-band Straylight (IRD-OPTS-R09)

The in-band straylight for the SPIRE spectrometer has been characterized as those contributions to the measured spectrum that are due to the channel fringes. In order to quantify this straylight contamination, the integrated spectral power was derived from those portions of the measured interferograms that contain the channel fringes. This fringe spectral power was then compared to the integrated spectral power derived from the portion of the interferogram near the position of zero path difference, which was free of channel fringes. The ratio of the measured fringe power to the source power for each active detector pixel is shown in Table 9.

The measured in-band contribution due to the channel fringes fell below the 5% straylight requirement (IRD-OPTS-R09) for all detector channels but one. The one channel that exceeded the straylight requirement was SLWC3, for which the ratio of the straylight power to the source power was found to be 6% of the source power.

Pixel	SQRT(Fringe Power / Source Power) [%]	Pixel	SQRT(Fringe Power / Source Power) [%]
SLWA1	3.10	SSWA1	2.05
SLWA2	1.82	SSWA2	2.08
SLWA3	3.67	SSWA3	2.29
SLWB1	1.55	SSWA4	1.90
SLWB2	2.65	SSWB1	1.51
SLWB4	2.95	SSWB2	1.86
SLWC1	3.78	SSWB3	2.26
SLWC3	6.05	SSWB4	1.85
SLWC4	4.11	SSWB5	2.47
SLWC5	4.91	SSWC1	1.22
SLWD1	1.55	SSWC2	1.67
SLWD2	2.81	SSWC3	1.98
SLWD3	2.82	SSWC4	2.11
SLWD4	2.36	SSWC5	3.39
SLWE1	3.56	SSWC6	2.61
SLWE2	1.73	SSWD1	1.48
SLWE3	3.69	SSWD2	1.51
		SSWD3	1.65
		SSWD4	2.65
		SSWD6	2.20
		SSWE1	1.42
		SSWE2	1.81
		SSWE3	2.15
		SSWE4	2.72
		SSWE5	2.46
		SSWE6	1.98
		SSWF1	1.28
		SSWF2	1.59
		SSWF3	1.95
		SSWF4	2.50
		SSWF5	1.48
		SSWG1	2.16
		SSWG2	1.85
		SSWG3	2.16
		SSWG4	2.66

Table 9: Measured straylight in-band power as a percentage of in-band source power from the PFM4 test campaign

8.6 Dead Time (IRD-SMEC-R05)

The plots featured in Figure 3 show the filtered SMEC speed as a function of time for the different PID control settings studied during the PFM4 test campaign. Each speed curve in the plots shown has been shifted such that t=0 corresponds to the end of the previous scan. As can be seen from the plots in Figure 3, the dead-time is independent of the SMEC PID control setting.

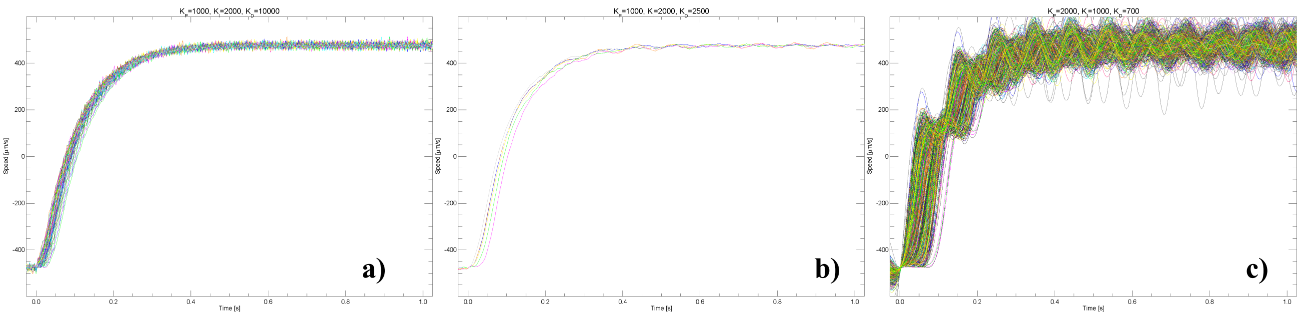

Figure 3: SMEC scan dead-time for the three PID control settings investigated during the PFM4 test campaign. Each figure is a plot of SMEC speed versus time from end of previous scan. PID control settings: a) Kp=1000, Ki=2000, Kd=10000; b) Kp=1000, Ki=2000, Kd=2500; c) Kp=2000, Ki=1000, Kd=700. Note that the speed curves shown here have been filtered for clarity.

8.7 Spectrometer mirror speed and position stability (IRD-SMEC-R08, IRD-SMEC-R09)

As discussed in §3.1.13, during the PFM4 test campaign the SMEC was tested using three sets of PID control parameters. The speed and position jitter were measured and found to be dependant on the PID settings, and two of the three settings studied were found to meet the requirements for mirror speed and position stability (IRD-SMEC-R08 and IRD-SMEC-R09). The results for the speed and position stability are presented in Table 10.

PID Settings	Unfiltered		Filtered	
	Speed Jitter, RMS [μm/s]	Position Jitter, RMS [μm]	Speed Jitter, RMS [μm/s]	Position Jitter, RMS [μm]
Kp=1000, Ki=2000, Kd=10000	360	1.00	5.5	0.15
Kp=1000, Ki=2000, Kd=2500	30	0.58	6.4	0.15
Kp=2000, Ki=1000, Kd=700	50	0.85	40	0.62

Table 10: Speed and position stability for the SMEC PID settings studied during the PFM4 test campaign

A further investigation was undertaken in order to assess how the increased speed and position jitter affected the resultant spectra. To do so, test observations were chosen such that the only significant difference between them were the SMEC PID control settings. The measured interferograms were then transformed to spectra and, for each spectral sample, the signal-to-noise ratio was evaluated.

The observations chosen for this study and their test conditions are summarized in Table 11 below.

OBSID	PID Control Settings	# of scans	Temperature [K]		
			CBB	SCALA	SCALB
0x300111B4	Kp=1000 Ki=2000 Kd=10000	4	6.71	4.66	4.58
0x300112FA	Kp=1000 Ki=2000 Kd=2500	8	6.69	4.63	4.56
0x300114C8	Kp=2000 Ki=1000 Kd=700	8	6.71	4.67	4.59

Table 11: Parameters of the observations chosen for the detailed speed and position stability study

The data recorded from each of the observations listed in Table 11 were processed in order to produce a set of medium-resolution spectra. Then, for each spectral bin of each pixel and for each observation, the average and standard deviation were evaluated. From these quantities, an estimate of the spectral signal-to-noise ratio was derived. Figure 4 shows plots of the measured spectral intensity and SNR for two of the spectrometer detector pixels; pixel A1 from the SLW array and pixel E4 from the SSW array.

As can be seen from the plots in Figure 4a and Figure 4c, the measured spectral intensities are quite similar, regardless of the PID control setting. This is not surprising given that the settings of the observed sources were similar from observation to observation. The plots in Figure 4b and Figure 4d show the measured spectral signal-to-noise ratio for the three observations. The spectral SNR plots demonstrate that, while there is a large difference between the observations in terms of the unfiltered and filtered speed and position stability (see Table 10), the resultant effect on the spectral noise is minimal

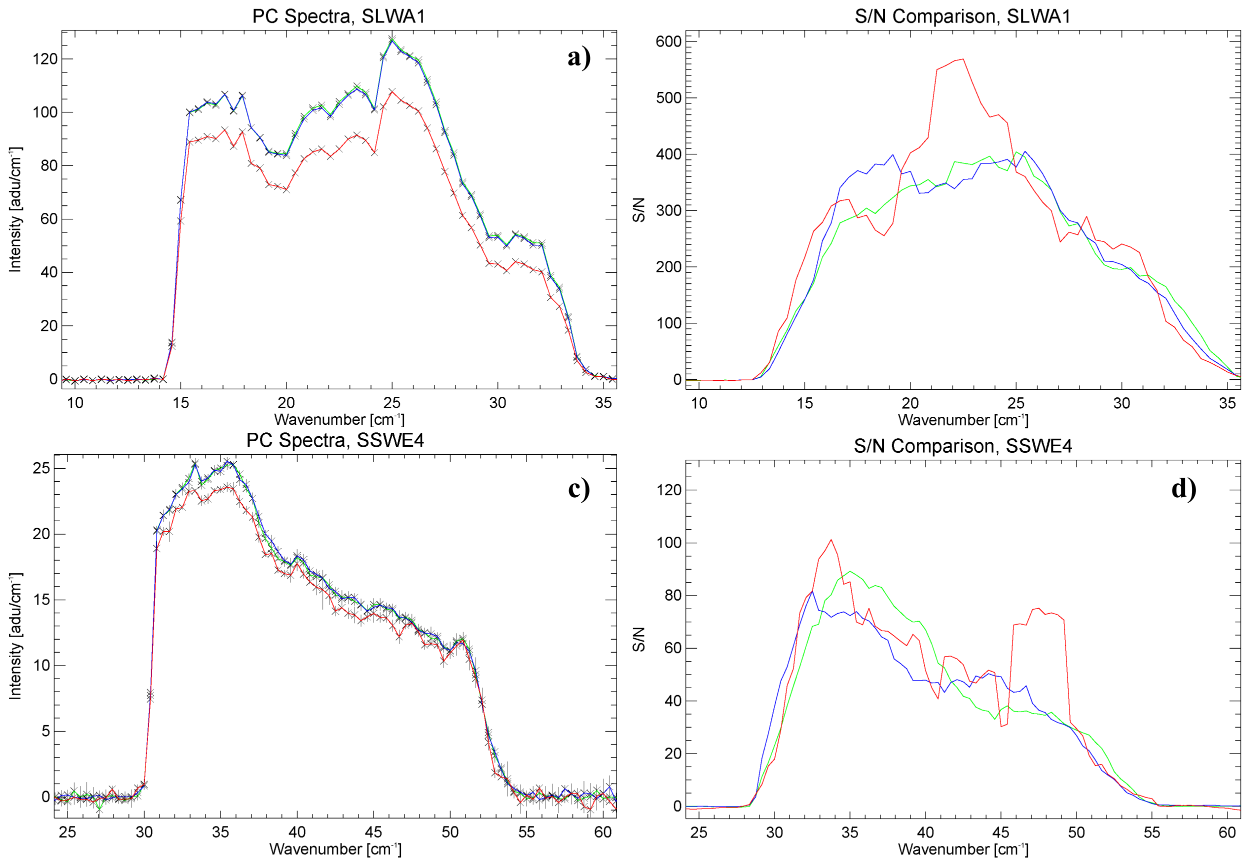

Figure 4: Measured Spectral Intensity and Spectral SNR. a) Measured spectral intensity for channel SLWA1; b) Spectral SNR for channel SLWA1; c) Measured spectral intensity for channel SSWE4; d) Spectral SNR for channel SSWE4. In each plot there are three curves, each of which corresponds to a difference set of SMEC PID control parameters: the **RED** curve corresponds to Kp=1000, Ki=2000, Kd=10000; the **BLUE** curve corresponds to Kp=1000, Ki=2000, Kd=2500; the **GREEN** curve corresponds to Kp=2000, Ki=1000, Kd=700.