

Calibration products for the SPIRE imaging spectrometer

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This document has been prepared for the express purpose of reviewing the calibration scheme for the SPIRE imaging Fourier transform spectrometer. Specific areas of concern are highlighted in yellow.

Table of Contents

- 1. Acronyms.....3
- 2. Scope4
- 3. The data processing pipeline for the SPIRE iFTS5
- 4. Calibration Products relating to the SPIRE iFTS5
 - 4.1 Detector tables.....5
 - 4.1.1 SCalSpecChanGain.....5
 - 4.1.2 SCalSpecBolPar6
 - 4.1.3 SCalSpecDerParam.....7
 - 4.1.4 ScalSpecPixTimeConst8
 - 4.1.5 SCalSpecChanTimeOff.....9
 - 4.1.6 SCalSpecOffsetHist10
 - 4.2 Spectrometer specific tables.....11
 - 4.2.1 ScalSpecLvdtOe.....11
 - 4.2.2 SCalSpecOeOpd.....13
 - 4.2.3 SCalSpecSmecZpd.....15
 - 4.2.4 SCalSpecBandEdge17
 - 4.2.5 SCalSpecGlitch18
 - 4.2.6 SCalSpecTeleRsrF19
 - 4.2.7 SCalSpecScalRsrF20
 - 4.2.8 SCalSpecScalEm.....21
 - 4.2.9 SCalSpecScalTempHist22
 - 4.2.10 SCalSpecModEff23
 - 4.2.11 SCalSpecScalVig25
 - 4.2.12 ScalSpecTeleVig27
 - 4.2.13 SCalSpecBesselFilter29
 - 4.2.14 SCalSpecNlp30
 - 4.2.15 SCalSpecStray.....32
 - 4.2.16 SCalSpecILS33
 - 4.3 Spatial information tables35
 - 4.3.1 SCalSpecFlat.....35
 - 4.3.2 SCalSpecPixAngOff36
 - 4.3.3 SCalSpecPsf.....37
 - 4.3.4 SCalSpecCross.....39
 - 4.4 BSM related tables.....40
 - 4.4.1 SCalSpecBsmOps40
 - 4.4.2 SCalSpecBsmPos42

1. Acronyms

Acronym	Description
BSM	Beam Steering Mirror
FIR	Far-Infrared
FTS	Fourier Transformation Spectrometer
iFTS	Imaging Fourier transform spectrometer
ILS	Instrumental Line Shape
LVDT	Linear Variable Differential Transformer
OE	Optical Encoder
OPD	Optical Path Difference
PSF	Point Spread Function
SCal	Spectrometer calibrator
SDI	Spectrometer Detector Interferogram
SDT	Spectrometer Detector Timelines
SMEC	Spectrometer mechanism
ZPD	Zero Path Difference

2. Scope

Fourier Transformation Spectrometers (FTS) are commonly used in infrared astronomy. SPIRE features an imaging FTS (iFTS) based on two bolometric detector arrays for the wavelength ranges from 200 – 330 μm and 300 – 670 μm . FTS systems allow for stringent and accurate spectral calibration if done correctly. This document gives a description for each calibration product on the SPIRE data product definitions web-page (www.spire.rl.ac.uk/consortium/icc/product_definitions/) and adds one more calibration data product. It aims to give a comprehensive overview of all products required to fully calibrate the SPIRE iFTS. It details the following aspects for each calibration product:

- Name
- Description, including Next Steps, i.e. how to further develop this product in the near future
- Contents
- Applicable data processing tasks
- Measurement and analysis procedure
- Application procedure
- Current status (this covers “**specified**”, i.e. whether the product is specified in detail, “**implemented**”, i.e. whether the product is implement within SPIRE DP, “**dummy-filled**”, i.e. whether a product has been populated with guesstimates to be used within SPIRE DP, “**accurately-filled**”, i.e. whether a product has been populated with data that are derived to reasonable accuracy and is ready for launch)

The following entries from Tanya’s SPIRE Calibration Plan are currently missing:

- **Astronomical Source Requirements**
- **Flight Phase**

The top level headings follow the SPIRE Calibration Plan, draft 0.2, from January 12, 2005. This document spells out the technical aspects of the calibration products in more detail than the calibration plan. This document should be integrated into the calibration plan to avoid any inconsistencies.

The requirements for the calibration of the SPIRE imaging FTS are spelled out explicitly in the module description of the SPIRE Fourier Transform task, version 1.5, issued in early May 2007.

Missing calibration products:

- **Channel Number Mapping Table**
- **Channel Mask Table**
- **Telemetry Parameter Conversion Table**

3. The data processing pipeline for the SPIRE iFTS

The flowchart below shows the structure of the data processing tasks for the SPIRE iFTS.

4. Calibration Products relating to the SPIRE iFTS

4.1 *Detector tables*

4.1.1 **SCalSpecChanGain**

4.1.1.1 **Description**

This product contains the LIA and JFET gains required to convert the detector readouts in ADU to Volts. A value for each gain is required for every detector channel.

The offsets applied in the electronics are handled in a separate stream. Do they require a respective calibration product?

4.1.1.2 **Contents**

Spectrometer Channel Gain Table for SSW:

- Channel Name
- LIA Gain
- JFET Gain

Spectrometer Channel Gain Table for SLW:

- Channel Name
- LIA Gain
- JFET Gain

4.1.1.3 **Applicable data processing tasks**

- Detector Response

4.1.1.4 **Measurement and analysis procedure**

TBD

4.1.1.5 **Application procedure**

See description of the Detector Response task.

4.1.1.6 **Current status**

Specified:	Yes
Implemented:	Yes
Dummy-filled:	Yes
Accurately-filled:	Yes

4.1.2 SCalSpecBolPar

4.1.2.1 Description

This product contains fixed detector parameters needed for detector processing. These parameters inform the correction of the detector timeline based on a detailed understanding of the bolometers.

4.1.2.2 Contents

Spectrometer Bolometer Parameter Table for SSW

- Reference Temperature for Bolometer [K]
- Channel Name
- Load Resistance (+ve bias) [Ohms]
- Load Resistance (-ve bias) [Ohms]
- Reference Temperature for Bolometer Resistance [K]
- Electrical Capacitance of Cable [F]
- Electrical Capacitance at Temperature T0 [W/K]
- Exponent for Temperature Dependence of Bolometer Thermal Conductivity

Spectrometer Bolometer Parameter Table for SLW

- Reference Temperature for Bolometer [K]
- Channel Name
- Load Resistance (+ve bias) [Ohms]
- Load Resistance (-ve bias) [Ohms]
- Reference Temperature for Bolometer Resistance [K]
- Electrical Capacitance of Cable [F]
- Electrical Capacitance at Temperature T0 [W/K]
- Exponent for Temperature Dependence of Bolometer Thermal Conductivity

4.1.2.3 Applicable data processing tasks

- Detector Response

4.1.2.4 Measurement and analysis procedure

TBW Is it correct to assume that this has to be taken from ground-based measurements and will not be updated during flight?

4.1.2.5 Application procedure

See description of the Detector Response task

4.1.2.6 Current status:

Specified:	Yes
Implemented:	Yes
Dummy-filled:	No
Accurately-filled:	Yes

4.1.3 SCalSpecDerParam

Is this required or useful? If so, shouldn't it be an intermediate product (cf. SDI) and not a calibration product? This could also be useful for QC and/or health monitoring.

4.1.3.1 Description

This product contains the detector parameters that are derived during processing but which are needed for later processing steps (or which may be of interest to the observers).

4.1.3.2 Contents

Derived Parameter for each Channel:

- Time [s]
- Bolometer Resistance [Ohms]
- Error on Bolometer Resistance [Ohms]
- Bolometer Temperature [K]
- Error on Bolometer Temperature [K]
- Bolometer Conductance [W/K]
- Error on Bolometer Conductance [W/K]

4.1.3.3 Applicable data processing tasks

- Detector Response

4.1.3.4 Measurement and analysis procedure

See description of the Detector Response task.

4.1.3.5 Current status

Specified:	Yes
Implemented:	No
Dummy-filled:	No
Accurately-filled:	No

4.1.4 ScalSpecPixTimeConst

4.1.4.1 Description

Currently, the thermal response of each detector is modeled as a single pole RC filter. The resulting time constant is used to correct for the responsivity of the detectors to illumination of known frequency. The time constant will be affected by the operating conditions of the detectors (temperature, bias, background loading, etc.) and may have to be determined under a range of these conditions to create a matrix that will allow us to pick the optimum conditions for instrument operation.

Next steps: Check consistency for various observations during ground-based test campaigns. Identify relevant parameter space. How accurate does this calibration have to be? Decide whether we have to re-compute the time constants for each set of observations or whether we can work with one calibration product.

4.1.4.2 Contents

Spectrometer Pixel Time Constants Table for SSW Pixels:

- Pixel Name
- Time Constant [Seconds]
- Error on Time Constant [Seconds]

Spectrometer Pixel Time Constants Table for SLW Pixels:

- Pixel Name
- Time Constant [Seconds]
- Error on Time Constant [Seconds]

4.1.4.3 Applicable data processing tasks

- Time Domain Phase Correction

4.1.4.4 Measurements and analysis procedure

Continuum measurements at various detector bath temperatures, various bias settings, varying background loading, scan speeds, ...

The time constant of a bolometer can be derived by applying the inverse of the 7 pole Bessel times the RC filter with a varying time constant until the interferograms overlap optimally (or until the SNR in the spectral domain is maximized). NB: This is somewhat time-consuming.

4.1.4.5 Application procedure

Combine the 7 pole Bessel filter from the read-out electronics with the RC filter from the thermal behavior and apply the inverse of this filter profile to the SDT.

4.1.4.6 Current status

Specified:	Yes
Implemented:	Yes
Dummy-filled:	Yes
Accurately-filled:	No

4.1.5 SCalSpecChanTimeOff

4.1.5.1 Description

This product contains the time offsets for individual pixel data relative to the overall 'frame time' that is recorded with the data. These offsets are due to the time required to read out each pixel. It can be assumed that these time offsets are constant throughout the mission.

Next steps: Implement and populate product. Develop the API of the Spectrometer Detector Interferogram (SDI) class to take this product into account.

4.1.5.2 Contents

Spectrometer Channel Time Offset Table for SSW Channels

- Channel Name
- Time Offset relative to single array readout [s]
- Time Offset relative to full array readout [s]

Spectrometer Channel Time Offset Table for SLW Channels

- Channel Name
- Time Offset relative to single array readout [s]
- Time Offset relative to full array readout [s]

4.1.5.3

4.1.5.4 Applicable data processing tasks

- API of the SDT product

4.1.5.5 Measurement and analysis procedure

Values are known from component testing at CEA.

4.1.5.6 Application procedure

Subtract time offsets from detector timelines.

4.1.5.7 Current Status

Specified:	Yes
Implemented:	No
Dummy-filled:	No
Accurately-filled:	No

We have the times from CEA. Can/should we verify them?

4.1.6 SCalSpecOffsetHist

This is not a formal calibration product and will not be necessary anymore once the AOT has a Building Block dedicated to setting the offsets. This product should be retained to work with ground-based data.

4.1.6.1 Description

This product stores the signal offset (in raw ADU) which are set from time to time for each channel of the instrument. This allows the signal offset to be added back to the measured detector signal by the pipeline EDP task. Final implementation for the format of this file is TBD. In the current implementation, each pixel has a separate column in the table and every time a new signal offset is set, a new row is added with a time-stamp to keep track when the offsets were applied.

4.1.6.2 Contents

Spectrometer Channel Offset History Table for SSW Channels

- Time [s]
- SSWA1 [ADU]
- SSWA2 [ADU]
- SSW## [ADU]

Spectrometer Channel Offset History Table for SLW Channels

- Time [s]
- SLWA1 [ADU]
- SLWA2 [ADU]
- SLW## [ADU]

4.1.6.3 Applicable data processing tasks

- EDP

4.1.6.4 Current Status

Specified:	Yes
Implemented:	Yes
Dummy-filled:	Yes
Accurately-filled:	No

4.2 Spectrometer specific tables

4.2.1 ScalSpecLvdtOe

4.2.1.1 Description

The SPIRE iFTS uses a Linear Variable Differential Transformer (LVDT) to provide absolute metrology of the mirror scan mechanism in the vicinity of ZPD. The DC voltage provided by the LVDT is referenced to the mechanical position of the stage mechanism. This is done by relating the LVDT signal to the count from the Optical Encoder (OE), which, in turn, is referenced to the end stop. The Calibration Product SCalSpecLvdtOe provides this conversion. Because the LVDT suffers from hysteresis, forward and reverse conversion tables are required.

Next steps: Check consistency of relationship between LVDT ~ OE. Compare the accuracy of the metrology provided by the LVDT and the OE close to ZPD.

4.2.1.2 Contents

SpectrometerLVDT to OE conversion table – forward

- LVDT DC signal [V]
- Optical Encoder []
- Error on Optical Encoder []

SpectrometerLVDT to OE conversion table – reverse

- LVDT DC signal [V]
- Optical Encoder []
- Error on Optical Encoder []

4.2.1.3 Applicable data processing tasks

- Create Interferogram

4.2.1.4 Measurement and analysis procedure

The LVDT can be calibrated against the OE by exercising the stage mechanism in forward and reverse mode. Any standard observation from the ground-based test campaigns or in-flight operations in continuous scan mode can be used to perform this calibration.

The measured DC signals from the LVDT can be referenced against the counts from the OE. Through repeated measurements the accuracy of this calibration can be increased. Over the lifetime of the instrument, this calibration will become more and more accurate as more suitable data sets become available.

4.2.1.5 Application procedure

The LVDT serves as a back-up for the OE and it is not clear whether it will be useful or not. The accuracy of the LVDT metrology close to ZPD may be superior when compared to the OE. This is TBC.

The OE position can be derived by looking up (with a suitable interpolation (linear/spline) if necessary) the OE value corresponding to the LVDT voltage measured at a certain point in time.

4.2.1.6 Current status

Specified:	Yes
Implemented:	No
Dummy-filled:	No
Accurately-filled:	No

4.2.2 SCalSpecOeOpd

4.2.2.1 Description

SCalSpecOeOpd serves to convert the count from the optical encoder to an optical path difference (OPD) for each pixel in order to take into account the changing OPD as a function of off-axis angle.

NB: Conversion to OPD assumes that ZPD has been determined accurately (see the calibration product containing ZPD). The latest work on the position of ZPD has shown that ZPD depends on input port and input source (SCal2 or SCal4).

The proposal outlined below suggests not to perform conversion from mechanical position to OPD until actually performing the Fourier transform. This implies that the interferograms returned by the SCal and telescope removal tasks have to be lined up correctly. This can either be done in the SCal and Telescope Removal tasks or in the FT task.

Next steps: Confirm how reliable the reset at the cold stop is. How often will the OE be reset?

4.2.2.2 Contents:

Spectrometer OE to OPD conversion table for each pixel in SSW:

- Optical Encoder
- Error on Optical Encoder
- Optical Path Difference for each channel [cm]

Spectrometer OE to OPD conversion error table for each pixel in SSW:

- Optical Encoder
- Error on Optical Encoder
- Error on Optical Path Difference for each channel [cm]

Spectrometer OE to OPD conversion table for each pixel in SLW:

- Optical Encoder
- Error on Optical Encoder
- Optical Path Difference for each channel [cm]

Spectrometer OE to OPD conversion error table for each pixel in SLW:

- Optical Encoder
- Error on Optical Encoder
- Error on Optical Path Difference for each channel [cm]

4.2.2.3 Applicable data processing tasks

- Fourier Transform

4.2.2.4 Measurement and analysis procedure

1) Measurements of a broad-band continuum source will lead to a strong illumination at ZPD. When taking forward and reverse scans, the highest detector signal will occur slightly displaced in mechanical position due to the low-pass filtering at detection. Applying a filter composed of the filter of the read-out

electronics and the RC filter from the thermal behavior of the bolometers will be a very accurate measurement of ZPD (see section 4.1.4 ScalSpecPixTimeConst).

2) Measurements of a sources dominated by line features at well-known frequencies will allow us to calibrate the OPD grid away from ZPD. Multiplying the wavenumber grid by a number slightly greater than one in the spectral domain will line up the measured with the expected line positions. The same multiplication factor can then be applied to the OPD grid.

NB: In principle, a direct calibration of the OPD grid is preferable to allow for OPD-dependent calibration and not one number fits the whole OPD range. However, suitable sources (one or two lines only) may not exist.

4.2.2.5 Application procedure

The count from the optical encoder is transformed into OPD for each pixel in the two detector arrays. A suitable interpolation is used to derive an OPD value for counts of the optical encoder that are not listed in the calibration product.

4.2.2.6 Current status:

Specified:	Yes
Implemented:	No
Dummy-filled:	No
Accurately-filled:	No

4.2.3 SCalSpecSmecZpd

4.2.3.1 Description

This product provides the optical encoder value and LVDT value at ZPD for each pixel. The ZPD values will be different for the telescope port, SCal2, and SCal4.

Next steps: Update product and add additional datasets to allow for differences between ZPD due to different input sources.

4.2.3.2 Contents

Spectrometer Optical Encoder at ZPD when **telescope** port is dominant for SSW:

- Pixel Name
- Optical Encoder at ZPD
- Error on Optical Encoder at ZPD
- LVDT DC Signal at ZPD
- Error on LVDT DC Signal at ZPD

Spectrometer Optical Encoder at ZPD when **telescope** port is dominant for SLW:

- Pixel Name
- Optical Encoder at ZPD
- Error on Optical Encoder at ZPD
- LVDT DC Signal at ZPD
- Error on LVDT DC Signal at ZPD

Spectrometer Optical Encoder at ZPD when **SCal2** is dominant for SSW:

- Pixel Name
- Optical Encoder at ZPD
- Error on Optical Encoder at ZPD
- LVDT DC Signal at ZPD
- Error on LVDT DC Signal at ZPD

Spectrometer Optical Encoder at ZPD when **SCal2** is dominant for SLW:

- Pixel Name
- Optical Encoder at ZPD
- Error on Optical Encoder at ZPD
- LVDT DC Signal at ZPD
- Error on LVDT DC Signal at ZPD

Spectrometer Optical Encoder at ZPD when **SCal4** is dominant for SSW:

- Pixel Name
- Optical Encoder at ZPD
- Error on Optical Encoder at ZPD
- LVDT DC Signal at ZPD
- Error on LVDT DC Signal at ZPD

Spectrometer Optical Encoder at ZPD when **SCal4** is dominant for SLW:

- Pixel Name
- Optical Encoder at ZPD
- Error on Optical Encoder at ZPD

- LVDT DC Signal at ZPD
- Error on LVDT DC Signal at ZPD

4.2.3.3 Applicable data processing tasks

Whenever a conversion to OPD occurs

4.2.3.4 Application procedure

Subtract ZPD from the OE count or the LVDT signal.

4.2.3.5 Current Status

Specified:	Yes
Implemented:	Yes
Dummy-filled:	Yes
Accurately-filled:	Yes

4.2.4 SCalSpecBandEdge

4.2.4.1 Description

This product contains the frequencies at which the overall spectral response of the detectors falls to 50% of the average in-band spectral response for all pixels in the SLW and SSW detector arrays.

From the instrument requirements: The spectral out of band rejection of the filtering on the instrument shall be such as to prevent contamination of the survey data by any non-legitimate source emission.

Next steps: Fill product from ground-based data.

4.2.4.2 Contents

Spectrometer Band Edges for SSW

- Pixel Name
- Low Frequency Edge [cm-1]
- High Frequency Edge [cm-1]

Spectrometer Band Edges for SLW

- Pixel Name
- Low Frequency Edge [cm-1]
- High Frequency Edge [cm-1]

4.2.4.3 Applicable data processing tasks

- Phase Correction
- Fourier Transform
- SCal?

4.2.4.4 Measurement and analysis procedure

Measurements of a continuum source (black body at two given temperatures to control for systematic errors in one observation); take the difference of the two measurements; divide out the difference of the profiles of the input source (Planck curve); take an average in the single-moded transmission region of SLW (17 cm^{-1}) and SSW (34.5 cm^{-1}); compute where the spectrum equals half that average.

It is important to check for spectral leaks in the MIR and NIR as bright stars etc will otherwise appear as legitimate sources. Contamination by light at higher frequencies can be tested very effectively by changing the sampling frequency only very slightly (e.g. by changing the stage speed slightly) and looking for any spectral line features that move significantly. NB: This would not be captured in this calibration product.

4.2.4.5 Current status:

Specified:	Yes
Implemented:	No
Dummy-filled:	No
Accurately-filled:	No

4.2.5 SCalSpecGlitch

4.2.5.1 Description

This product is a container for all deglitching-related processing settings which will serve as default values when executing the deglitching tasks. E.g., it will contain threshold values used to identify interferogram glitches, such as those caused by cosmic rays.

NB: This is more a product to set default values for user setting relating to deglitching, rather than a calibration product in the usual sense. Is this the appropriate way of doing this?

Next steps: Define the overall approach to deglitching. Specify the calibration product in detail.

4.2.5.2 Contents:

Spectrometer Glitch Threshold Table for SMEC scanning

- Glitch Threshold []
- TBD

4.2.5.3 Applicable data processing tasks

- Time-domain Deglitching
- Interferogram Deglitching

4.2.5.4 Measurement and analysis procedure

Take a small set of measurements and visually identify glitches and set the threshold to where it maximizes the number of correctly identified glitches while minimizing the number of false positives. From ground-based and the early in-flight phases.

TBD

4.2.5.5 Application procedure

See the description of the Deglitching tasks.

4.2.5.6 Current status

Specified:	Yes
Implemented:	No
Dummy-filled:	No
Accurately-filled:	No

4.2.6 SCalSpecTeleRsrF

4.2.6.1 Description

This product details the transmission efficiency from the astronomical source to the SPIRE spectrometer detectors. It will encapsulate components of the SPIRE spectrometer, the Herschel optics, and the telescope emissivity.

Next steps: Implement product, using data from ground-based testing.

4.2.6.2 Contents

Transmission profile of the sky-port per pixel for SLW

- Wavenumber [cm-1]
- Relative efficiency []

Transmission profile of the sky-port per pixel for SSW

- Wavenumber [cm-1]
- Relative efficiency []

4.2.6.3 Applicable data processing tasks

- Telescope Removal
- Spectral Response

4.2.6.4 Measurement and analysis procedure

(At least two) Sets of measurements of the telescope during the cool-down phase (or any other opportunity where we can expect the telescope to change temperature) with SCal kept constant at a point where we can record unclipped interferograms.

The difference of the two measurements divided over assumed Planck curves (at measured or derived telescope temperatures) gives the profile of the spectral efficiency of the SPIRE telescope port times the efficiency profile due to the optical chain from the telescope to SPIRE times the telescope emissivity. NB: We will need access to telemetry detailing the temperature of the telescope as a function of time.

Results should be cross-checked with those from the other instrument or spacecraft teams. At least some of them (PACS) also need to characterize the thermal properties of the telescope.

4.2.6.5 Application procedure

See description of the Telescope Removal task.

4.2.6.6 Current status

Specified:	No
Implemented:	No
Dummy-filled:	No
Accurately-filled:	No

4.2.7 SCalSpecScalRsrf

4.2.7.1 Description

This product details the transmission efficiency from SCal2 and SCal4 to the SPIRE spectrometer detectors.

Next steps: Define, implement, and populate calibration product.

4.2.7.2 Contents

Transmission profile from SCal2 per pixel for SLW

- Wavenumber [cm-1]
- Relative efficiency []

Transmission profile of the SCal2 per pixel for SSW

- Wavenumber [cm-1]
- Relative efficiency []

Transmission profile from SCal4 per pixel for SLW

- Wavenumber [cm-1]
- Relative efficiency []

Transmission profile of the SCal4 per pixel for SSW

- Wavenumber [cm-1]
- Relative efficiency []

4.2.7.3 Applicable data processing tasks

- Telescope Removal
- Spectral Response

4.2.7.4 Measurement and analysis procedure

Several sets of measurements of SCal2/4 while the telescope is stable and looking at a dark region in the sky.

The difference of two measurements divided over the assumed Planck curves at assumed emissivities gives the optical spectral efficiency profile from SPIRE SCal2/4.

4.2.7.5 Application procedure

See description of the SCal removal task.

4.2.7.6 Current status

Specified:	No
Implemented:	No
Dummy-filled:	No
Accurately-filled:	No

4.2.8 SCalSpecScalEm

Is this necessary? Shouldn't the SCal emissivities be part and parcel of the SCalSpecScalRsrfr?

4.2.8.1 Description

This product contains the SCAL emissivities table.

4.2.8.2 Contents

TBD. The SCal task currently allows for emissivity as a function of wavenumber.

4.2.8.3 Applicable data processing tasks

- SCal

4.2.8.4 Measurement and analysis procedure

4.2.8.5 Application procedure

See description of the SCal task.

4.2.8.6 Current status

Specified:	Yes
Implemented:	Yes
Dummy-filled:	Yes
Accurately-filled:	No

4.2.8.7

4.2.9 SCalSpecScalTempHist

This product seems to be redundant as any long-term trends in the SCal emissivity would already be tracked by the updated SCalRsrf products.

4.2.9.1 Description

This product tracks the long term variation in the read-out temperatures for the SCAL sensors compared to their actual temperatures.

4.2.9.2 Contents

Temperature history for SCAL

- Time [s]
- Readout Temperature [K]
- Actual Temperature [K]

Temperature history for SCAL-2

- Time [s]
- Readout Temperature [K]
- Actual Temperature [K]

Temperature history for SCAL-4

- Time [s]
- Readout Temperature [K]
- Actual Temperature [K]

4.2.9.3

4.2.9.4 Applicable data processing tasks

- SCal

4.2.9.5 Measurement and analysis procedure

TBD.

4.2.9.6 Application procedure

TBD.

4.2.9.7 Current status

Specified:	Yes
Implemented:	No
Dummy-filled:	No
Accurately-filled:	No

4.2.10 SCalSpecModEff

4.2.10.1 Description

This product provides a correction for the modulation efficiency as a function of mechanical position. Modulation efficiency is understood for this purpose as a purely multiplicative change to the interferogram modulation with OPD. Any changes in the interferogram baseline due to the changing overlap between the telescope and SCal beams are treated by the vignetting calibration products (see sections 4.2.11 and 4.2.12).

Next steps: Review available data and their consistency.

4.2.10.2 Contents

Modification Efficiency for SSW

- Optical Encoder
- Error on Optical Encoder
- Modification Efficiency for each channel

Modification Efficiency Errors for SSW

- Optical Encoder
- Error on Optical Encoder
- Error in Modification Efficiency for each channel

Modification Efficiency for SLW

- Optical Encoder
- Error on Optical Encoder
- Modification Efficiency for each channel

Modification Efficiency Errors for SLW

- Optical Encoder
- Error on Optical Encoder
- Error in Modification Efficiency for each channel

4.2.10.3 Applicable data processing tasks

- Modulation Correction

4.2.10.4 Measurement and analysis procedure

Fit apodized interferogram to measurements of sources with prominent line features (preferably monochromatic emitters). Alternatively, the instrumental line shape can be measured.

4.2.10.5 Application procedure

Divide the interferogram after baseline correction by the derived apodization function

4.2.10.6 Current status

Specified:	Yes
Implemented:	No

Dummy-filled: No
Accurately-filled: No

4.2.11 SCalSpecScalVig

4.2.11.1 Description

These two products provide a correction for the vignetting as the SMEC moves away from ZPD. The vignetting causes a variation in total power in the interferogram with OPD due to a changing beam filling factor with SMEC position. The correction is an additive offset versus OPD which is applied to the interferogram. There are two products with identical structure: one for SCal and one for the Telescope.

The line width could be affected by vignetting of the off-axis pixels and increased beam shear at off axis positions. This is both a design driver and needs verification at instrument level. The maximum resolution is governed both by the physical movement of the SMEC and by any loss in fringe contrast due to beam shear and vignetting. This can only be characterized at instrument level.

Next steps: Check reproducibility of vignetting curves. Are there differences between SCal2 and SCal4? If so, then add respective datasets.

4.2.11.2 Contents

Spectrometer SCAL Vignetting Table:

Vignetting for the SCal port for SSW

- Optical Encoder
- Error on Optical Encoder
- Vignetting Correction for each channel

Vignetting Errors for the SCal port for SSW

- Optical Encoder
- Error on Optical Encoder
- Error on Vignetting Correction for each channel

Vignetting for the SCal port for SLW

- Optical Encoder
- Error on Optical Encoder
- Vignetting Correction for each channel

Vignetting Errors for the SCal port for SLW

- Optical Encoder
- Error on Optical Encoder
- Error on Vignetting Correction for each channel

4.2.11.3 Applicable data processing tasks

- Baseline correction

4.2.11.4 Measurement and analysis procedure

At least two sets of measurements of continuum sources with SCal/telescope

dominant to subtract out one of the ports. This product should make use of the continuously on-going observations in order to make use of as large an experience base as possible in order to outperform a straightforward 2nd order fit to each individual interferogram.

Second order polynomial fit of the difference interferograms.

4.2.11.5 Application procedure

Subtract baseline from measured interferogram.

4.2.11.6 Current status

Specified:	Yes
Implemented:	No
Dummy-filled:	No
Accurately-filled:	No

4.2.12 ScalSpecTeleVig

4.2.12.1 Description

These two products provide a correction for the vignetting as the SMEC moves away from ZPD. The vignetting causes a variation in total power in the interferogram with OPD due to a changing beam filling factor with SMEC position. The correction is an additive offset versus OPD which is applied to the interferogram. There are two products with identical structure: one for SCAL and one for the Telescope.

The line width could be affected by vignetting of the off-axis pixels and increased beam shear at off axis positions. This is both a design driver and needs verification at instrument level. The maximum resolution is governed both by the physical movement of the SMEC and by any loss in fringe contrast due to beam shear and vignetting. This can only be characterized at instrument level.

Next steps: Check reproducibility of vignetting curves.

4.2.12.2 Contents

Spectrometer Telescope Vignetting Table:

Vignetting for the Telescope port for SSW

- Optical Encoder
- Error on Optical Encoder
- Vignetting Correction for each channel

Vignetting Errors for the Telescope port for SSW

- Optical Encoder
- Error on Optical Encoder
- Error on Vignetting Correction for each channel

Vignetting for the Telescope port for SLW

- Optical Encoder
- Error on Optical Encoder
- Vignetting Correction for each channel

Vignetting Errors for the Telescope port for SLW

- Optical Encoder
- Error on Optical Encoder
- Error on Vignetting Correction for each channel

4.2.12.3 Applicable data processing tasks

- Baseline correction

4.2.12.4 Measurement and analysis procedure

At least two sets of measurements of continuum sources with SCal/telescope dominant to subtract out one of the ports. This product should make use of the continuously on-going observations in order to make use of as large an

experience base as possible in order to outperform a straightforward 2nd order fit to each individual interferogram.

Second order polynomial fit of the difference interferograms.

4.2.12.5 Application procedure

Subtract baseline from measured interferogram.

4.2.12.6 Current status

Specified:	Yes
Implemented:	No
Dummy-filled:	No
Accurately-filled:	No

4.2.13 SCalSpecBesselFilter

4.2.13.1 Description

This product details all the parameters necessary to reconstruct the frequency response function of the read-out electronics.

Next steps: Specify and populate product.

4.2.13.2 Contents

Values of the resistances R and capacitances C as used in the read-out electronics. TBD in detail.

4.2.13.3 Applicable data processing tasks

- Time Domain Phase Correction

4.2.13.4 Measurement and analysis procedure

By design.

4.2.13.5 Application procedure

Multiply with frequency response from the thermal response and then see Create Interferogram.

4.2.13.6 Current status

Specified:	No
Implemented:	No
Dummy-filled:	No
Accurately-filled:	No

4.2.14 SCalSpecNlp

This product may be redundant once the phase from the two output ports has been removed.

4.2.14.1 Description

This product contains the known non-linear optical phase as a function of wavenumber. It may be useful to have a high resolution and low resolution version of the product. The wavenumber grid should range from 0 to 200 cm^{-1} . The wavenumber grid must be regularly spaced. The phase-error will be different depending on input and output port of the FTS, making it necessary to store four different phases.

The final aspect of the relative responsivity requirement that requires verification is the requirement to be able to make repeated observations of the same source and achieve the same answer in terms of the flux measured. In order to achieve this the detection system must be intrinsically temporally stable and we must have a method of determining its stability both on ground and in flight. One method of doing this is to measure the signal from a known and stable source with the instrument in a known operating conditions at intervals that sample a wide frequency range. This will show whether there are changes in the instrument responsivity over time and there characteristic frequencies.

Phase should always be between $-\pi/2$ and $\pi/2$ or some such?

4.2.14.2 Contents

Non-linear Optical Phase

- Wave Number [cm^{-1}]
- Telescope Phase for SSW
- Telescope Phase for SLW
- SCAL Phase for SSW
- SCAL Phase for SLW

Error in Non-linear Phase

- Wave Number [cm^{-1}]
- Error on Telescope Phase for SSW
- Error on Telescope Phase for SLW
- Error on SCAL Phase for SSW
- Error on SCAL Phase for SLW

4.2.14.3 Applicable data processing tasks

- Phase Correction

4.2.14.4 Measurement and analysis procedure

Determine the optical (in contrast to time-domain) phase by adding the averaged phase of forward from reverse scans.

In order to absolutely calibrate the equivalent flux from a small step in the calibrator output a blackbody can be placed in the beam of the instrument and set to give the same flux as used for the DC responsivity calibration. The instrument is set to its nominal operating condition (bias; temperature etc) and the calibrator cycled between on and off with a small output step to provide a stable output the calibrator may have to be driven at the upper end of its temperature range, therefore this step may be done on top of a DC pedestal. The net DC signal will be arranged to be the same by reducing the load from the external blackbody. This can be repeated for different flux levels and calibrator and detector operating conditions.

4.2.14.5 Application procedure

Multiplication with $\exp(-PCF)$ for double-sided interferograms or convolution with $FT-1(\exp(-PCF))$ for single-sided interferograms.

4.2.14.6 Current status

Specified:	Yes
Implemented:	Yes
Dummy-filled:	Yes
Accurately-filled:	No

4.2.15 SCalSpecStray

4.2.15.1 Description

The optical design of the instrument is intended to prevent radiation from outside the field of view of the two sub-instruments from reaching the detectors directly or via any of the mirrors in the optical chain. This design must be verified and an attempt made to identify if there are any straylight paths within the instrument for sources outside the instrument FOV. This calibration will remove the stray lights from the interferograms. Testing this will be very difficult.

Note that straylight is only a concern as far as it is modulated through the interferometer.

Does this calibration relate to channel fringes?

Next steps: Decide whether this product can be filled sensibly.

4.2.15.2 Contents

TBD

4.2.15.3 Applicable data processing tasks

- TBD

4.2.15.4 Measurement and analysis procedure

TBD

4.2.15.5 Application procedure

TBD

4.2.15.6 Current status

Specified:	No
Implemented:	No
Dummy-filled:	No
Accurately-filled:	No

4.2.16 SCalSpecILS

4.2.16.1 Description

This calibration product contains the instrumental line shape (ILS) vs. wavenumber. The ILS of an FTS should be a sinc function which introduces side-lobes to any unresolved spectral features that are not resolved by the instrument. For example, the ILS will become apparent for most spectral line measurements taken by the SPIRE iFTS.

Removing the ILS from spectral measurements while leaving the spectral resolution unchanged is not trivial. If spectral resolution can be sacrificed, then it may be sufficient to apodize interferograms in order to avoid confusion of side-lobes with line features. Possible candidate techniques to remove the ILS from spectra are de-convolution or forward-convolution of a model spectrum and minimization of the difference of the resulting spectral model and the measured spectrum. Both techniques introduce processing risks (inaccurate de-convolution, failure of the minimization to converge).

Alternatively, the ILS can be left as is in the spectrum. In this case, the extraction of line features has to take the ILS into account and fit the line features with the ILS rather than a generic Gaussian, Lorentzian, or sinc profile.

Next steps: It has to be clarified whether SPIRE data processing routines should produce spectra that show no trace of the characteristics of the instrument. If this is a requirement then the ILS has to be removed. If this is not a requirement, it may be preferable to deal with the ILS when analyzing and interpreting spectral data.

The ILS can also serve as a detailed QC or health monitor as it evaluates the complete instrument.

4.2.16.2 Contents

ILS per pixel as a function of wavenumber

- ILS []
- Wavenumber [cm-1]

4.2.16.3 Applicable data processing tasks

- TBD Either a dedicated ILS Removal task or down-stream data analysis tools (e.g. CASSIS).

4.2.16.4 Measurement and analysis procedure

The ILS should be derived from high SNR measurements of unresolved line features.

4.2.16.5 Application procedure

TBD

4.2.16.6 Current status

Specified:	No
Implemented:	No
Dummy-filled:	No
Accurately-filled:	No

4.3 Spatial information tables

4.3.1 SCalSpecFlat

What exactly does this refer to? If it only concerns the offset in the interferograms, then it is not required.

4.3.1.1 Description

This product contains the values defining the pixel to pixel variations caused by the optical arrangement of the instrument and telescope.

Next steps: Decide whether this calibration product is useful.

4.3.1.2 Contents

Spectrometer Flat Field for SSW Pixels

- Pixel Name
- Flat Field Value
- Error on Flat Field

Spectrometer Flat Field for SLW Pixels

- Pixel Name
- Flat Field Value
- Error on Flat Field

4.3.1.3 Measurement and analysis procedures

If PCAL produces enough flux then this would be an ideal source to monitor the flatfield, on the ground the cold black body can be used. As no astronomical source is flat, this may be done in flight via scanning a point source over each pixel in turn. It is likely that this will be referenced to the ZPD.

4.3.1.4 Current Status

Specified:	Yes
Implemented:	Yes
Dummy-filled:	Yes
Accurately-filled:	Yes

4.3.2 SCalSpecPixAngOff

4.3.2.1 Description

This product contains angular offsets from the telescope boresight (probably aligned with the central pixel).

4.3.2.2 Contents

Spectrometer Pixel Angular Offset Table for SSW Pixels

- Pixel Name
- Angular Offset in Z-direction [arcsecond]
- Error on Angular Offset in Z-direction [arcsecond]
- Angular Offset in Y-direction [arcseconds]
- Error on Angular Offset in Y-direction [arcsecond]

Spectrometer Pixel Angular Offset Table for SSW Pixels

- Pixel Name
- Angular Offset in Z-direction [arcseconds]
- Error on Angular Offset in Z-direction [arcsecond]
- Angular Offset in Y-direction [arcseconds]
- Error on Angular Offset in Y-direction [arcsecond]

4.3.2.3 Applicable data processing tasks

- Pointing

4.3.2.4 Measurement and analysis procedure

TBD by whom?

4.3.2.5 Application procedure

n/a

4.3.2.6 Current status

Specified:	Yes
Implemented:	Yes
Dummy-filled:	Yes
Accurately-filled:	Yes

4.3.3 SCalSpecPsf

The beam-size as a function of wavelength will be useful to know but only down-stream, when regridding the honeycomb onto a rectangular grid.

4.3.3.1 Description

Relative response of a pixel as a function of near beam position in the focal plane of the telescope is the point spread function. It defines the impulse response of the instrument to a point source and is also used in determination of the instrument throughput. The spatial impulse response function describes the shape of the angular response of an individual pixel in the bolometer arrays to a delta function or point source. The most obvious method of determining the impulse response function is to scan a point source across the field of view of an individual detector at the input focal plane of the telescope simulator. The use of a fully coherent source with a small angular spread and fully coherent phase is desirable as this can be modeled to a very high degree of fidelity and therefore de-convolution of the source from the measure response is very much easier. Another way to determine the point spread function is to measure the response of the instrument to a point source scanned across the image of the instrument cold stop as projected outside the instrument. The Fourier transform of this response gives the impulse response function of the instrument on the sky. Making the measurement in this fashion has the advantage that a source of reasonably extent can be used as it only has to be small compared with the size of the pupil image and the beams of all detectors can be measured simultaneously. The disadvantage of this method is that no phase information is found and so aberrations in the optics are not detected and the source will need to be carefully designed to avoid problems with straylight.

In principle measurement of the point spread function will give both the spatial extent of the intensity pattern at the focal plane – the equivalent waist radius, and by Fourier transform, the angular spread of the beam in the far field. However, because we only measure the intensity it is not always possible to unambiguously disentangle the effects of any multi-mode response of the feedhorns and aberrations caused by misalignment or other systematic errors in the telescope simulator and / or instrument optics. It is highly desirable therefore to make a direction measurement of the angular extent of the beam directly at the instrumental pupil image. This measurement also has the advantage of giving the beam filling factor compared to the full aperture of the telescope and is therefore a direct measurement of the point source coupling efficiency of the instrument. This product is used to correct the point spread.

Next steps: TBD.

4.3.3.2 Contents

Beam-size as a function of wavenumber per pixel

- Wavenumber [cm-1]
- TBD.

4.3.3.3 Measurement and analysis procedure

A small source is scanned across the location of the image of the instrument cold stop. All pixels are measured with a single measurement – the preferred source to use here is the FIR laser focused at the input focal plane of the telescope simulator. This gives a well defined illumination pattern on the telescope simulator pupil with a flat phase front. A blackbody source can also be used but this will be more difficult to interpret due to partial coherence and brightness problems. The image of the source is finely stepped over the position of the target pixel preferably in raster pattern to determine the 2-D impulse response. In principle this measurement should be made for each pixel in each array. This may prove to take too long and a minimum sub-set of pixels for which this measurement will be carried out will be identified – see also optical distortion measurement below. It is also possible that shorter cross patterns is used for some pixels rather than the full raster. Both types of measurement should be available. However this restricts the measurement to a single channel per scan and the comparison between the laser and a black body should be done. Although it is preferred that the full 2-D area of the pupil response is explored this may be impossible due to practical difficulties with implementation. At least a cross pattern measurement should be possible.

Describe the measurement procedure during flight.

4.3.3.4 Application procedure

- Regridding onto a regular grid on the sky.

4.3.3.5 Current Status

Specified:	No
Implemented:	No
Dummy-filled:	No
Accurately-filled:	No

4.3.4 SCalSpecCross

4.3.4.1 Description

There are two kinds of crosstalk: electrical crosstalk and optical crosstalk. If present, electrical crosstalk will be apparent from the fact that the pixels are grounded in four in one wire. The crosstalk table could consist of pixel id plus pixel ids of the other three pixels and their crosstalk levels. Optical crosstalk will be apparent if the PSF for a particular pixel is deviant from the PSF for other pixels in that part of the array, this may appear as ghosts. If this is a smooth function it may not be possible to distinguish the PSF from the crosstalk.

Next steps: TBD

4.3.4.2 Contents

$N \times (N-1)$ or $N \times 3$ (see the description above) matrix of cross-talk strength and error as a function of OPD (or wavenumber?).

4.3.4.3 Measurement and analysis procedures

Observations of a well-defined point source before a dark background with every single pixel.

NB: This may not fully correct for cross-talk in the case of extended sources.

4.3.4.4 Application procedure

Reduce the signal (ifgm or spectral domain) of a given pixel by the signal strength of the other pixels times the respective entry in the cross-talk matrix.

TBD.

4.3.4.5 Current Status

Specified:	No
Implemented:	No
Dummy-filled:	No
Accurately-filled:	No

Ground-based data are probably not suitable here because we can't be confident to actually have point sources.

4.4 BSM related tables

4.4.1 SCalSpecBsmOps

How will this be used in data processing? Is this used to control the instrument?

4.4.1.1 Description

This product defines the BSM operations for each different operating mode (e.g., POF1, POF2, etc.). There is a separate table dataset listing the ID position and matching chop and jiggle sensor values for each different mode. This allows a chop beam ID and a jiggle ID to be assigned to the real BSM positions in the Chop and Jiggle Timeline. There are additional columns to define the tolerance in matching chop and jiggle sensor values when making this comparison, so that the matched values falls within the range,

$$\text{chopSens} - \text{chopLoTol} < x < \text{chopSens} + \text{chopHiTol}$$

The table gives position in BSM raw sensor signal and this is converted to angle using BSM Positions Table.

4.4.1.2 Contents

Spectrometer BSM Operation Table for 4-point Jiggle Map

- Observation Mode ID
- Chop Bean Identifier
- Jiggle Position Identifier
- Sensor Signal in Chop Direction
- Negative Tolerance in Chop Sensor Signal
- Positive Tolerance in Chop Sensor Signal
- Sensor Signal in Jiggle Directions
- Negative Tolerance in Jiggle Sensor
- Positive Tolerance in Jiggle Sensor

Spectrometer BSM Operation Table for 16-point Jiggle Map

- Observation Mode ID
- Chop Bean Identifier
- Jiggle Position Identifier
- Sensor Signal in Chop Direction
- Negative Tolerance in Chop Sensor Signal
- Positive Tolerance in Chop Sensor Signal
- Sensor Signal in Jiggle Directions
- Negative Tolerance in Jiggle Sensor
- Positive Tolerance in Jiggle Sensor

4.4.1.3 Applicable data processing tasks

- Pointing

4.4.1.4 Measurement and analysis procedure

4.4.1.5 Application procedure

4.4.1.6 Current status

Specified:	Yes
Implemented:	Yes
Dummy-filled:	Yes
Accurately-filled:	Yes

4.4.2 SCalSpecBsmPos

How will this be used in data processing? For quality control?

4.4.2.1 Description

This product provides the calibration between BSM sensor signal in raw units (in chop and jiggle directions) and angular distance on the sky from its zero position (in spacecraft Y, Z coordinates).

4.4.2.2 Contents

Spectrometer BSM Position Table

- Sensor Signal in Chop Direction [ADU]
- Sensor Signal in Jiggle Direction [ADU]
- Angle in Spacecraft Y-Direction [arcseconds]
- Error in Y-Angle [arcseconds]
- Angle in Spacecraft Z-Direction [arcseconds]
- Error in Z-Angle [arcseconds]

4.4.2.3 Applicable data processing tasks

- Pointing

4.4.2.4 Measurement and analysis procedure

A point source is put on the center of a pixel at the nominal BSM position for that pixel. A small raster is then done with the BSM to check that the BSM position is correct. The raster will be fitted to find the center.

4.4.2.5 Application procedure

The pointing information for each pixel is adjusted according to the actual pointing of the BSM.

4.4.2.6 Current status

Specified:	Yes
Implemented:	Yes
Dummy-filled:	Yes
Accurately-filled:	Yes