Technical Note on the ICC Work Package: Fourier Transformation

SPIRE-UOL-NOT-002204

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Document History:

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0.1 draft	5 March 2004
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Table of Contents:

1. Distribution List

Dave Clements (ICL)

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2. Reference Documents

ID	Title	Author
RD1	SPIRE ICC Consolidated WorkPlan, 1.0 draft 2	Ken King
RD2	Operating Modes for the SPIRE Instrument, SPIRE-RAL-PRJ-000320	Bruce Swinyard
RD3	CDR HERSCHEL Micro-Vibration Analysis Report, H-P-2-ASP-AN-0773, issue 1	P. Lodereau

3. Applicable Documents

ID	Title	Author
~~Kunis, Potts, Steidl 2002~~AD1	Fast Fourier transform at nonequispaced knots, A user's guide to a C-library, 2002 http://www.math.mu-luebeck.de/potts/nfft/	Stefan Kunis, Daniel Potts, University of Lübeck, Germany and Gabriele Steidl, University of Mannheim, Germany
~~Potts, Steidl, Tasche 2001~~ AD2	Fast Fourier transforms for nonequispaced data: A tutorial. , 2001 In J. J. Benedetto and P. J. S. G. Ferreira, editors, Modern Sampling Theory: Mathematics and Applications, pages 247 - 270, Boston	Daniel Potts, Gabriele Steidl, and Manfred Tasche, University of Lübeck, Germany
~~Spencer 2003~~AD3	Phase Correction and Apodization, 2003	Locke Spencer, University of Lethbridge
~~Tahic 2004~~AD4	Apodization, Powerpoint Presentation, 2004	Margaret Tahic, University of Lethbridge
AD5	Data processing pipeline for a time-sampled imaging Fourier transform spectrometer, 2004 Proc. SPIE, Imaging Spectrometry X 5546, Denver	David Naylor, Trevor Fulton, Peter Davis, Ian Chapman, Brad Gom, Locke Spencer, John Lindner, Nathan Nelson-Fitzpatrick, Margaret Tahic, Gary Davis
AD6	SPIRE/FTS: MICRO-VIBRATIONS, 2004	Jean-Paul Baluteau, LAM

4. Acronyms

CALT	Calibration Team

CSA	Canadian Space Agency
DRCU	Detector Read-out and Control Unit
FFT	Fast Fourier Transformation
FOV	Field of view
FT	Fourier Transformation
HCSS	Herschel Common Software System
IA	Interactive Analysis
ICC	Instrument Control Centre
ICL	Imperial College London
IPAC	Infrared Processing and Analysis Center
ISDT	Instrument Software Development Team
JAC	Joint Astronomy Centre
JPL	Jet Propulsion Laboratory
LAM	Laboratoire d'Astrophysique de Marseille
OBST	Observations and Data Processing Team
OPD	Optical Path Difference
RAL	Rutherford Appleton Laboratory
SDS	Spectrometer Detector Spectrum
SDT	Spectrometer Detector Timeline
SMEC	Spectrometer Mechanical Unit
TBC	To be confirmed
TM	Telemetry
UoL	University of Lethbridge
ZPD	Zero Path Difference

5. Objective of this document

This document provides a comprehensive and detailed overview of the processes that go into the delivery of the ICC Work Package Fourier Transformation. It aims to collect and consolidate contributions from all involved groups and individuals.

6. Objective of Work Package

"Provide data processing steps and software modules to convert photometrically corrected detector data timeline into a spectrum using converted SMEC Data.

This involves assigning an Optical Path Difference to each detector sample, interpolating into an equally sample dataset (TBC), phase correction, apodization, and Fourier transformation." (RD1, 36)

7. Input

1. Spec Detector Timeline (SDT) ~~from the task 'Crosstalk'~~
2. SMEC timeline (SMECT)
3. HK timeline (HKT)

~~It is also assumed that additional metadata will be available, such as the operating parameters of the spectrometer~~

4. Calibration products:
    - LVDTDCSignal at ZPD
    - LVDTDCSignal to OPD
    - OpticalEncoder to OPD
    - Bad pixel mask~~.~~
    - Expected phase
    - Band limits

8. Output

1. Spectrometer Detector Interferogram (SDI) as an intermediary processing step.

~~1.~~2. Spectrometer Detector Spectrum (SDS) into the task 'Correct for Telescope'. (TBC)

~~2.Quality Control Bitmap for the SDS (and SDT?)~~

9. Milestones

~~July 2004~~March 2005: Definition of Data Products

~~January~~ September 2005: Delivery of Processing Modules

~~January~~ September 2005: Delivery of Conversion Data/Tables

10. Involved parties

~~*10.1.SPIRE teams*~~

- ~~Other users of input data: DRCU, in particular photometer bolometer arrays, spectrometer bolometer arrays, and SMEC (JPL ???; LAM, Jean-Paul Baluteau, …)~~
- ~~Other users of output data: DRCU, in particular bolometer arrays (JPL ???; IPAC, LAM, Jean-Paul Baluteau, …)~~
- ~~OBST (ICL, Matt Fox)~~
- ~~Quality Control (ICL, Dave Clements)~~

~~Trend Analysis (RAL, Sunil Sidher?)~~

~~CALT (RAL, Tanya Lim)~~

~~ISDT (RAL, Steve Guest)~~

~~10.2. Institutions~~

~~ICL: Matt Fox (OBST, photometer deglitching), Dave Clements (Quality Control)~~

~~LAM: Jean-Paul Baluteau et al. (spectrometer deglitching, SMEC data)~~

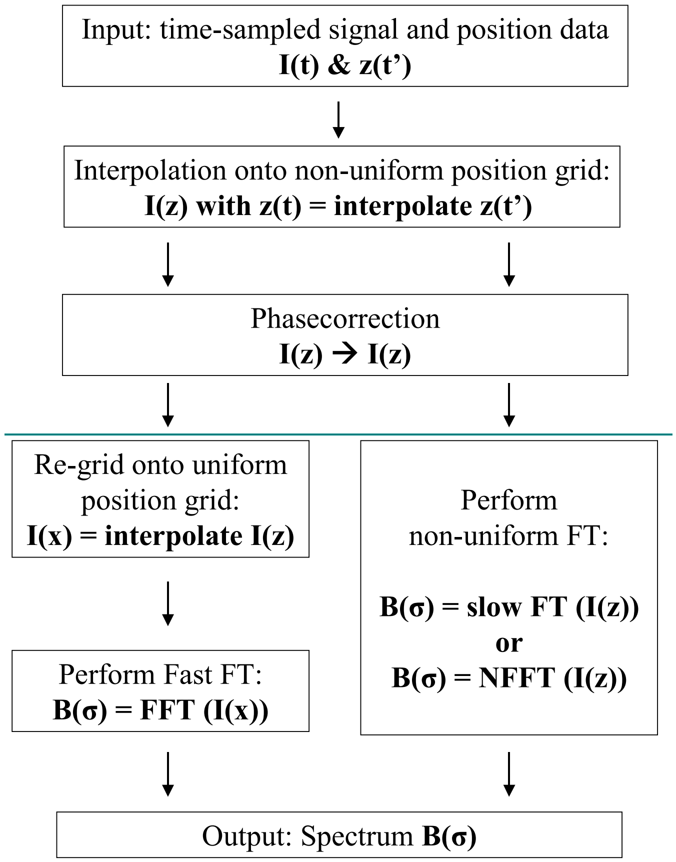
~~RAL: Tanya Lim (CALT), Steve Guest (ISDT), Sunil Sidher? (Trend Analysis)~~

~~Other providers/users of in/output data (JPL!?, …)~~

11. Implementation options

Data reduction for the SPIRE FTS data is a linear process with three mandatory and one optional step: Interpolation of the stage position, phasecorrection, and Fourier Transformation are necessary elements of this process. Apodization is an option depending on user choice. See appendix A.

The two qualitatively different operational modes for the spectrometer, continuous scan and step-and-integrate (see RD2), will require slightly different processing. The following sections are written with the continuous scan mode in mind. See the section on open issues for special considerations on step-and-integrate. The option of processing non-uniformly sampled data (AD1, AD2) was explored in depth (AD5), but efficient and accurate methods for the processing of regularly sampled data have been identified. The former option will only be pursued if the processing of regularly sampled data turns out to be clearly inferior or infeasible for some reason.



~~**Figure 1: Process options to perform the FT**~~

11.1. Interpolation of the stage position

~~Data from the DRCU are time-sampled where the~~The position of the stage is measured at ~240Hz (TBC whether 250Hz): **z(t')** and the detectors are read out at a rate of 80Hz: **I(t)**, i.e., position is sampled more frequently than signal[1]. The first step is therefore to interpolate the position so that for each signal reading a position is ~~made~~ available: **I(z)**. Please note that the resulting interferogram will be non-uniform, i.e. the position grid is not equidistant ($z \neq i \cdot \Delta z$ with $i \in Z$).

This is a good point to convert mechanical position into optical path difference. For that purpose, ZPD must be known. ZPD will be retrieved from a calibration file[2].~~A routine to identify ZPD or the central maximum will be necessary for this.~~ An early conversion has the advantage of avoiding later confusion. ~~However, i~~It should be noted that the details of

[1] This document uses **z** to refer to non-uniform position data and **x** to refer to uniform, i.e. equidistant position data.

[2] A routine to identify ZPD or the central maximum will be necessary for the reduction of data from early test campaigns when the required calibration product is not yet available.

determining ZPD will have an impact on the resulting phase and therefore phasecorrection.

The OPD is not the same for all the detectors and depends on their angle β from the optical axis: OPD(β) = OPD(0) x cos(β) Where β_{max} = (FOV/2) x (D/d) with D = telescope diameter (3300 mm) and d = pupil diameter (25 mm). So for a detector at the edge of the FOV (2.6') β = 2.86 degree. The effect is therefore in the order of cos(2.86), i.e. 0.12%. Because the differences in OPD due to the off-axis placement of pixels are so small, all detector timelines will be interpolated onto the same OPD grid. This has the great advantage of a harmonized spectral resolution between pixels which greatly simplifies spectral analysis across pixels.

11.2. Phasecorrection

An important step in the data reduction is the phase correction. Beamsplitters, discrete time-sampling, ~~direction of the stage~~the thermal inertia of the bolometers, and electronic filtering all introduce phase errors to the data. ~~A routine to correct for the phase errors needs to be developed. Two approaches seem to be possible: Either~~Knowledge of the actual phase can be gained either from studying and modeling all components that contribute to the phase error ~~and develop a phase correction on this basis~~ or from analyzing~~e~~ the measured phase ~~resulting from the measurements and use the empirical data as the basis for phasecorrection~~ (~~Spencer 2003~~AD3)[3]. The latter option assumes that some double-sided portion for each interferogram is available. It will be necessary for the phase-correction to distinguish between single-sided and double-sided interferograms.

~~Phasecorrection is shown in as a processing step that operates on non-uniform data. It may be preferable to correct for phase errors on equidistant data if available.~~

11.3. Fourier Transformation

~~At this juncture, one can either re-grid the non-uniform interferogram onto a uniform interferogram I(x) and then use a standard FFT or perform an FT on the non-uniform interferogram (see **Error! Reference source not found.**). The former option may cause problems because the re-gridding may introduce artifacts.~~ Assuming that interferograms have been interpolated onto a uniform OPD grid, the Fourier Transformation becomes trivial. The interferogram will be butterflied and FFT'ed.~~The latter option assumes to compute an FT which is a slow operation of $O(n^2)$ if a fast implementation for the non-uniform FT is not feasible. Efficient algorithms to perform a non-uniform FT have been proposed (Potts, Steidl, Tasche 2001) and implemented in a C-library (Kunis, Potts, Steidl 2002). Their adequacy for the problem at hand is to be verified.~~

[3] ~~To date, the LAM has pursued the modeling and the UoL the empirical approach.~~

11.4. Apodization

Data products can be enhanced under certain circumstances by applying apodization functions to the interferogram. Apodization functions reduce ringing while losing spectral resolution at the same time.

Optional apodization will be based on a selection of widely used apodization functions and the Norton-Beer expansion of apodization functions to allow the selection of a suitable apodization function based on the reduction of spectral resolution (see ~~Tahic 2004~~AD4).

~~NB: The apodization function can be applied to the non-uniform or the uniform interferogram for the re-gridding option for the FT (see section 11.3). It will be necessary to explore which one of these two options is preferable.~~

12. Open Issues

- Is NFFT a ~~n~~more efficient and ~~precise~~ accurate ~~software package~~ approach to perform an FT on non-uniformly sampled data? If so, is it feasible to translate the relevant parts of this package into Java? How will phasecorrection be performed in this case?

~~How to perform the phasecorrection?~~

~~Does phasecorrection have a problem with non-uniform interferograms?~~

~~Should apodization functions be applied to the uniform or the non-uniform interferograms?~~

- The Quality Control bitmap for the interferograms (SDT) does not translate naturally into a bitmap for the spectrum (SDS). Shall we freeze and push along the bitmap for the interferograms and create a second bitmap for the spectra?
- As far as step-and-integrate is concerned: Is it better to average signals for each stage position and then FT the resulting interferogram or should n different FTs be performed and then averaged? Or should we not average and output n different spectra?
- Based on the predictions for the micro-vibration environment are correct (RD3, AD6) a deconvolution step is necessary to correct for the filtering due to the bolometer and the read-out electronics in the time domain.

~~Does this task have to meet performance requirements?~~

13. Checkpoints

Other users/OBST:

- Have all providers of input data agreed on its format?
- Have all users of the end product agreed on its format?

Quality Control:

- Are adequate flags for data quality and processing quality provided?

Trend Analysis:

- Are adequate flags for long-term trends in the data quality and processing quality provided?

CALT:

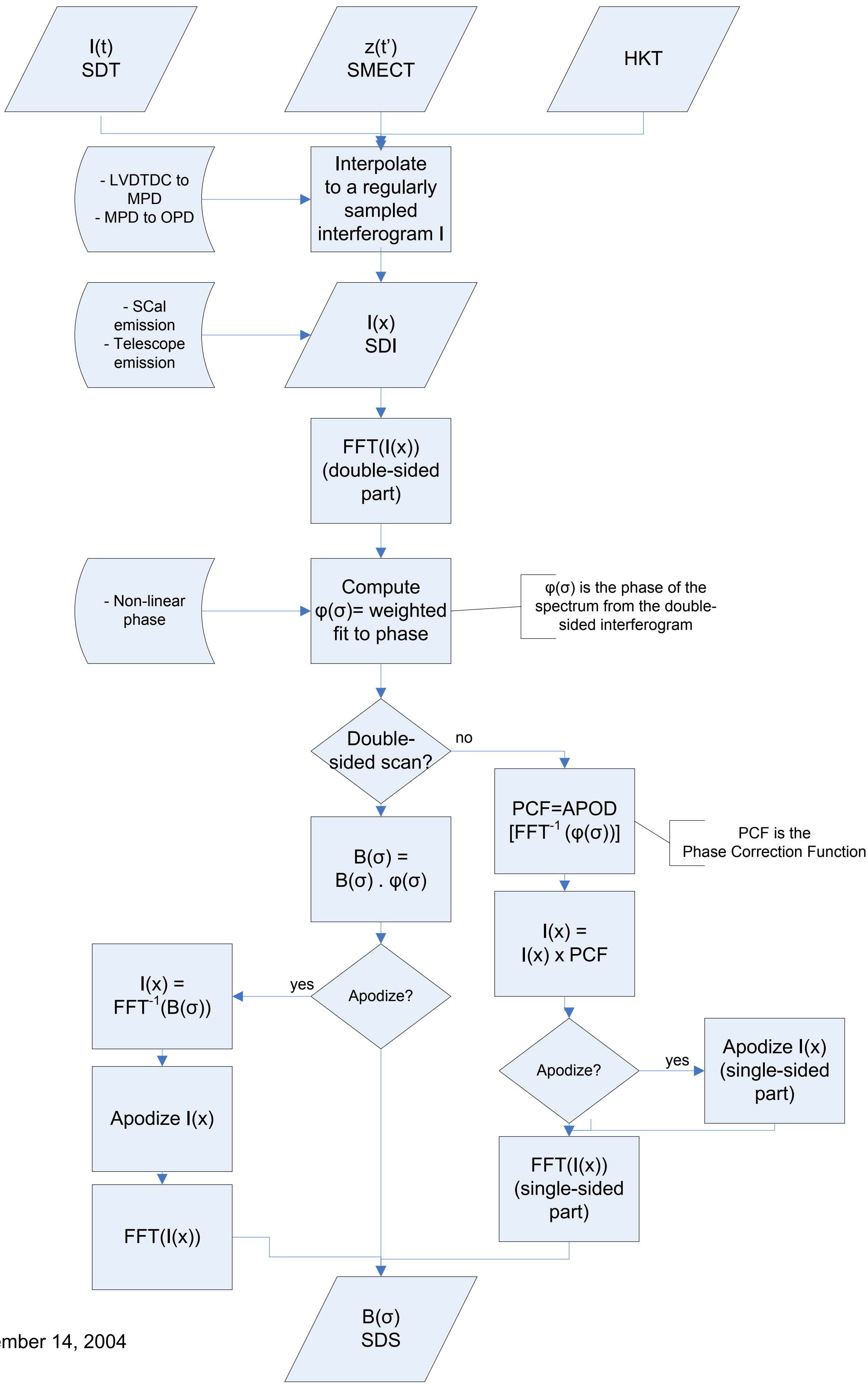
- Have all necessary calibration tables been identified?
- Can all necessary calibration tables be provided by the scheduled tests/operations?

ISDT:

- Are all software requirements (coding conventions, exception handling, test procedures, documentation, benchmarking) met?

Appendix A: overview of FTS data processing

Flow chart for the work package Fourier Transformation



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