Port Compensation Using the Herschel/SPIRE Imaging Fourier Transform Spectrometer

Locke D. Spencer*, David A. Naylor*, Trevor R. Fulton†, Jean-Paul Baluteau‡,
Peter A.R. Ade§, Peter W. Davis† and Bruce M. Swinyard¶
*Department of Physics, University of Lethbridge,
Lethbridge, Alberta, Canada, www.uleth.ca/phy/naylor/group.shtml
†Blue Sky Spectroscopy, Lethbridge, Alberta, Canada, www.blueskyinc.ca
‡Laboratoire d'Astrophysique de Marseille, Marseille, France, www.oamp.fr/lam/
§School of Physics and Astronomy, Cardiff University,Cardiff, Wales, UK, www.astro.cardiff.ac.uk
¶Space Science and Technology Department, Rutherford Appleton Laboratory,
Chilton, England, UK, www.sstd.rl.ac.uk

***Abstract*—In Fourier Transform Spectroscopy (FTS), observations of a broad continuum source produce an interferogram which has a large dynamic range around the position of zero optical path difference (ZPD). The process of port compensation involves a broadband spectral source placed at the second, complementary input port of an FTS, reducing the dynamic range requirements of the detector system. Port compensation is particularly advantageous in cases where blackbody emission from the focusing optics of an instrument produce a radiative background which dominates a much weaker source signal, as is often found in far-infrared and submillimetre astronomy. The Herschel/SPIRE imaging FTS uses a calibration source (SCAL) to compensate for the emission of the passively cooled telescope optics. In the case of Herschel, it will not be possible to determine the temperature and emissivity of the telescope accurately until after launch; therefore SCAL must have sufficient variability to accommodate this uncertainty. Although simple in theory, port compensation of the SPIRE FTS is non-trivial since it is not possible to match precisely the spectral signature of the Herschel optics over their possible temperature and emissivity parameter space. Typically only partial spectral cancelation can be expected which causes complications in the subsequent data processing and spectral analysis. We discuss the specific challenges to processing data from the SPIRE imaging FTS when both input ports are well balanced and present respective results from the ground-based test campaigns of the SPIRE imaging FTS flight model.**

I. INTRODUCTION

The SPIRE FTS is of a Mach-Zehnder design which gives ready access to both input and output ports of the spectrometer (Fig. 1) to enable both: 1) more efficient use of source photons, and 2) a reduction of interferogram dynamic range through compensation of undesired instrument background emission with the secondary input port. The SCAL calibration source is located at the second input port to the SPIRE FTS in order to complement the blackbody emission (T=80K, $\epsilon = 0.02$)[1] from the Herschel telescope. This work discusses the port compensation scheme used in SPIRE and the data processing challenges which accompany well balanced input ports.

II. PFM TESTING

The Proto-flight Model (PFM) instrument test campaigns are conducted in order to space-qualify and calibrate the SPIRE instrument prior to launch. PFM testing simulates the flight conditions of SPIRE as accurately as possible within a laboratory setting by placing the instrument at cryogenic temperatures under vacuum[2]. As is planned during telescope observation, SCAL is tuned to various temperatures during PFM testing in order to compensate for the intensity of radiation entering the primary FTS input port.

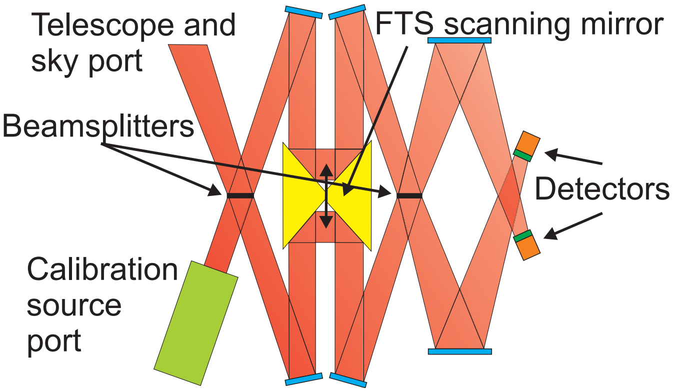

Fig. 1. Diagram of the SPIRE imaging FTS including primary and compensation input ports.

One of the experiments performed during PFM testing was to hold the cold blackbody (CBB) at a constant temperature at the primary input port while heating/cooling SCAL across its range of temperature settings. Figure 2 illustrates one such experiment where the CBB was maintained at $6.7K$ and SCAL was cooled from $20.0K$ (dotted curve) to $8.7K$ (dashed curve) while medium resolution interferograms were being recorded. The interferograms are expected to be symmetric about ZPD. As is observed in Figure 2.a, when one of the FTS ports is dominant the interferograms demonstrate Optical Path Difference (OPD) symmetry about ZPD. As SCAL cools, however, a point is reached where SCAL emission approaches that of the CBB; at this point the interferogram modulation is difficult to observe (offset curve labeled $10.8K$, Fig. 2.a).

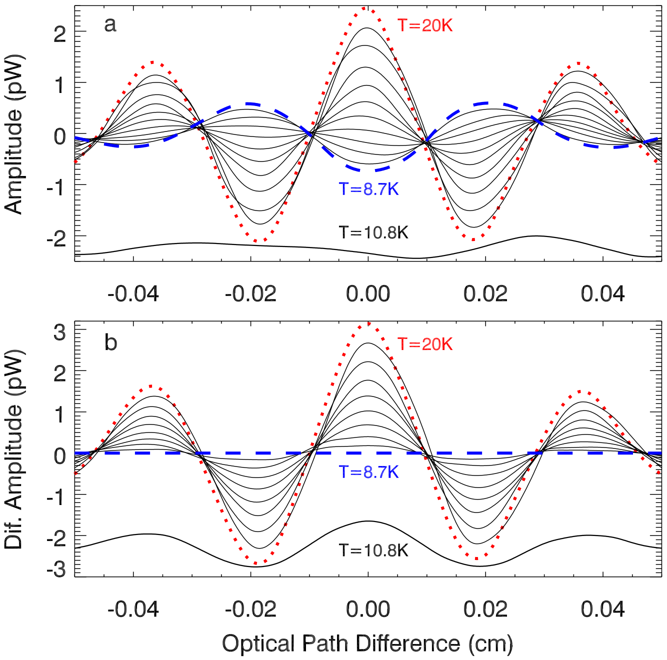

Fig. 2. Recorded interferograms for CBB fixed at $6.7K$ and SCAL cooling from $20K$ to $8.7K$ (decreasing amplitude at ZPD). a) Measured interferograms. Optimum compensation for this set of observations occurs near SCAL at $10.8K$ (shown offset for clarity); the symmetry is clearly lost. b) Differences of interferograms in part (a) reveal the interferogram symmetry.

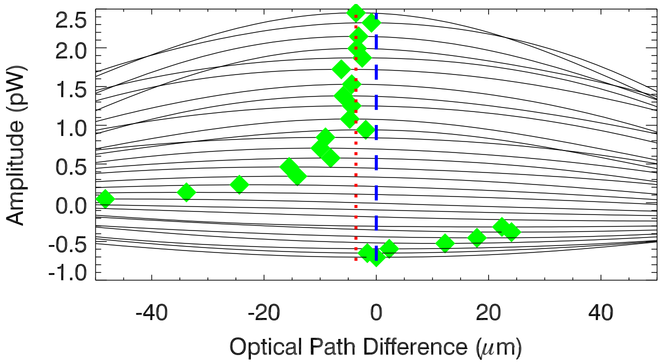

Fig. 3. ZPD region of the CBB constant/SCAL cooling interferograms. Diamonds identify the maximum observed modulation (ideally at ZPD) for each recorded interferogram. The dotted/dashed vertical bars (scheme matches Figure 2) represent the ZPD location for each input port. There is a $\sim 3\mu m$ OPD port dependant difference on the location of ZPD.

III. DUAL PORT DATA PROCESSING

It is common practice in Fourier spectroscopy to correct for phase errors in the measured interferogram signal. In the case of single port dominant interferograms (Fig. 2.a) this symmetry is maintained, albeit at the cost of increased dynamic range in the interferogram. FTS phase correction will restore symmetry to single port dominant interferograms; allowing Fourier transformation of the symmetric interferogram to generate the desired spectrum.[3] In the case where the second port is used to reduce the dynamic range of the interferogram signal through compensation (Fig. 2.a), this symmetry is lost and standard phase correction techniques cannot be applied. It is shown that by use of a differencing technique (Fig. 2.b) the symmetry is restored.

The region of maximum interferogram modulation is known as the location of ZPD in single port dominant interferograms. Figure 3 shows the location of the extrema for each interferogram as SCAL cools (positive modulation for the SCAL port, negative for the CBB port). As can be seen, the location of these extrema varies within this data set in a predictable fashion. The summation of two symmetric signals should be symmetric, however, if the modulation from each port is symmetric about a different OPD (e.g. the dotted and dashed vertical bars on Figure 3), then the resulting interferogram loses its symmetry as is observed.

Where there is no single axis of symmetry, traditional FTS phase correction methods will lead to erroneous results. A residual linear phase error in the spectrum will result due to the physical separation of each input port's location of ZPD. Phase correction is intrinsically a non-linear process and cannot correct for the inherent lack of symmetry resulting from the differing ZPD locations from the two input ports. Therefore the asymmetry between the complementary ports must be dealt with in the interferogram domain; only then can traditional phase correction be applied.

IV. CONCLUSION/CALIBRATION PLAN

With the configuration of SPIRE it is not possible to isolate directly the contribution of each input port to the recorded interferogram. The spectral signature of the Herschel input optics suite under flight conditions will remain unknown until instrument commissioning after telescope launch. The SPIRE FTS port calibration scheme must therefore be flexible enough to accommodate these, as yet unknown, conditions. Although the spectral contribution of SCAL is obtained through ground-based laboratory measurements, the contribution of the Herschel telescope will be measured during Herschel telescope in-flight commissioning observations as the primary mirror cools to operational temperature.

ACKNOWLEDGMENT

NSERC, Alberta Ingenuity, CSA, University of Lethbridge, STFC, and CNRS provide funding for this research. The authors also wish to acknowledge the SPIRE instrument test team at the Rutherford Appleton Laboratory and the Herschel/SPIRE consortium.

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