Phase Study of SPIRE PFM1 Spectrometer Data

version 1.0

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1 Introduction

This document describes the analysis of the measured interferogram phase of the SPIRE PFM1 spectrometer data. The purpose of this analysis is to study how the various optical elements within the SPIRE spectrometer affect the phase.

2 Background

The first step in characterizing the phase was to attempt to pinpoint the location of zero path difference for each detector. This was accomplished by two different methods; a linear phase method and an interpolation method. These methods are described below.

2.1 Linear Phase Method

If during the acquisition of an interferogram, the signal is not sampled at zero path difference (ZPD), a phase will result. From Fourier theory, a ZPD sampling error of δx results in a phase error equal to $2\pi\delta x\sigma$. In the spectral domain, this induced phase describes a linear function with a slope equal to $2\pi\delta x$. As a result, the amount by which the interferogram samples missed the ZPD position can be found by first fitting a linear function to the resultant phase then dividing this slope by 2π.

The linear phase method used to determine the position of zero path difference is similar to the one used by Jean-Paul Baluteau[1]:

1. Interpolate (using a cubic spline) the optical encoder timeline onto a regularly sampled mirror position timeline.
2. Interpolate (using a cubic spline) the detector signal timeline (per pixel) onto the mirror position timeline.
3. Choose a value in the mirror position timeline as ZPD and transform the interferogram to the spectral domain (Figure 1).
4. Evaluate the phase by Tan^{-1}(Im(Spectrum)/Re(Spectrum)) (Figure 2).
5. Fit a linear function, of the form $y=mx + b$, (weighted by the spectral amplitude) to that portion of the resultant phase based within the optical pass-band. If the phase rolls over from $-\pi$ to π or vice versa, this must be taken into account (Figure 2).
6. From the fit parameters, determine the actual ZPD position relative to the predicted ZPD position (Figure 3).

[1] Jean-Paul Baluteau, "*PFM1 Tests: electrical & optical dephasing*", presentation, 22 April 2005

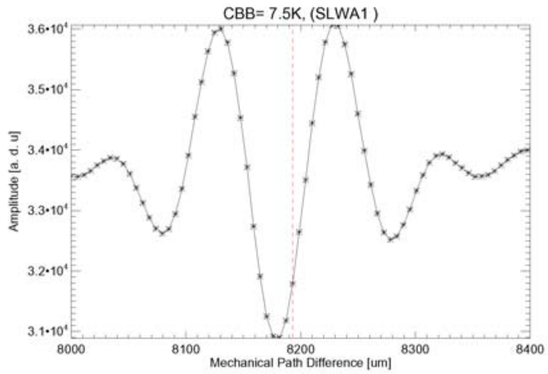

Figure 1: Sample interferogram, initial guess at ZPD. The dashed line shown denotes the initial guess at the ZPD position.

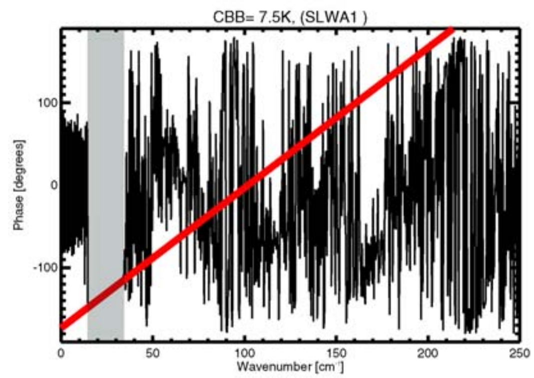

Figure 2: Sample phase spectrum. The phase spectrum shown here is derived from the sample interferogram above. The fit to the in-band phase is shown as the **red** line. The **grey** area corresponds to the SLW pass band.

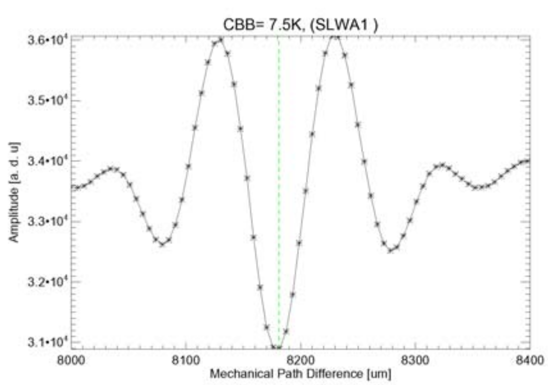

Figure 3: Sample interferogram, corrected ZPD. The dashed line shown here denotes the ZPD position derived from the initial guess and the linear fit to the resultant phase.

2.2 Interpolation Method

The position of zero path difference can also be determined by way of inspection of the recorded interferogram. The signal at ZPD is expected to have the largest amplitude since all observed frequencies interfere constructively/destructively when the moving mirror reaches that point. Therefore, one can determine the position of ZPD by the location of the signal with the largest amplitude. In order to improve the precision with this method, the observed interferogram is first interpolated (via sinc interpolation) onto a sampling grid that is much finer than the observed sampling interval.

The plots in Figure 4 show the curves resulting from the interpolation step and the derived ZPD positions.

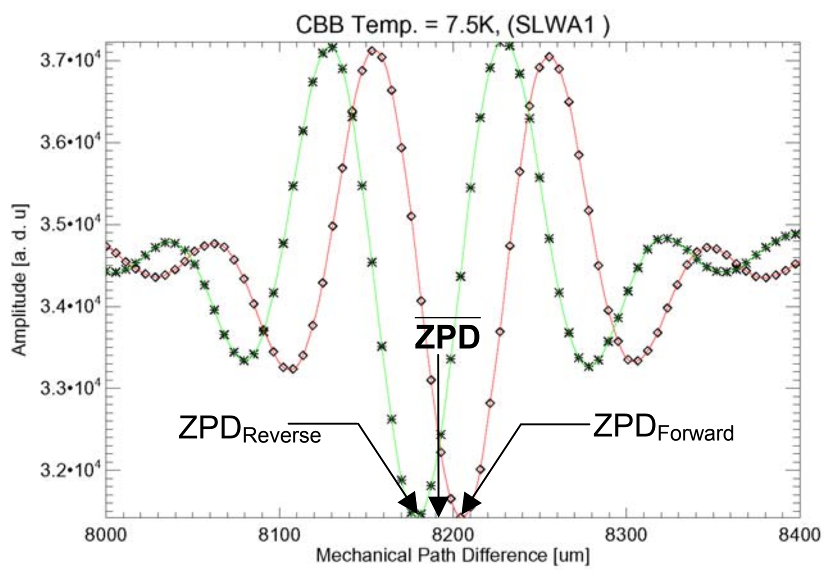

Figure 4: Sample forward (*) and reverse (◊) scans. The solid lines show the result of the interpolation step (**red**: forward, **green**: reverse). Also indicated are the derived ZPD positions for each scan and the average ZPD position.

It should be noted that for each of the methods used to determine the position of zero path difference, the forward scans and the reverse scans were evaluated separately. The final ZPD position was determined as the being the midpoint between ZPD for the forward scans and ZPD for the reverse scans.

3 Results

Using the two methods described in §2, the ZPD positions for each pixel in each array were derived. These values are shown numerically in Tables 1-4 and graphically in Figure 5. The colour-coded entries (, and) in the tables below correspond to the overlapping pixels for the two BDAs. The pixels shaded black are those on which no useful signal was recorded.

A			8192.3±0.3		8200.9±0.3		8211.4±0.7		
B		8191.5±0.4		8200.2±0.5		8209.8±0.3		8219.8±0.3	
C	8191.6±0.6		8199.7±0.2		8208.9±0.2		8218.8±0.2		8228.3±0.2
D		8199.5±0.3		8208.2±0.3		8217.7±0.3		8227.4±0.2	
E			8207.5±0.3		8216.6±0.3		8225.7±0.5		

Table 1: Derived ZPD Locations (units: SMEC mirror position in µm), SLW array, Interpolation Method

	G	F	E	D	C	B	A
7				8192.4±2.1			
			8192.3±1.1		8211.4±25.4		
6		8189.3±0.7		8203.1±0.5		8214.7±2.8	
	23236.9±14084.7		8199.8±1.0		8206.7±21.1		8221.6±0.6
5		11730.9±12409.7		24129.2±16943.9		8217.8±1.2	
	21726.4±15700.7		8202.2±0.7		8220.7±33.5		8224.9±0.3
4		8198.8±0.6		8208.7±4.6		8220.7±0.6	
	8195.3±0.5		8205.4±0.3		8216.1±0.7		8227.8±0.7
3		8201.8±0.4		8212.5±0.3		8223.5±0.3	
	8198.5±0.3		8208.7±0.4		8219.4±0.4		8230.3±0.3
2		8204.7±0.4		8215.2±0.6		8226.2±0.5	
			8211.5±0.5		8222.2±0.4		
1				8217.8±0.5			

Table 2: Derived ZPD Locations (units: SMEC mirror position in µm), SSW array, Interpolation Method

A		8192.4±0.3	8200.0±0.2	8209.5±0.2	
B	8191.7±0.3	8199.8±0.2	8208.8±0.2	8218.2±0.2	
C	8191.4±0.5	8199.0±0.2	8208.3±0.3	8217.8±0.2	8227.1±0.3
D	8198.7±0.2	8207.6±0.2	8216.9±0.1	8226.1±0.3	
E		8206.8±0.2	8215.4±0.1	8224.3±0.2	

Table 3: Derived ZPD Locations (units: SMEC mirror position in µm), SLW array, Linear Phase Method

	G	F	E	D	C	B	A
7				8191.6±0.9			
			8191.6±1.0		8219.7±66.2		
6		8187.8±1.1		8203.6±0.5		8216.4±2.9	
	8201.4±210.3		8199.1±0.7		8212.0±3.6		8223.2±0.4
5		8190.9±250.9		8174.3±263.7		8219.2±0.8	
	8118.4±330.1		8202.1±0.9		8214.6±2.2		8226.7±0.4
4		8198.9±0.4		8210.2±1.1		8222.3±0.5	
	8195.3±0.3		8206.2±0.4		8217.7±0.5		8229.6±0.5
3		8202.4±0.6		8213.4±0.4		8224.8±0.6	
	8199.1±0.5		8209.6±0.3		8220.6±0.5		8232.1±0.5
2		8205.6±0.3		8216.5±0.4		8227.9±0.5	
			8212.8±0.4		8223.6±0.5		
1				8219.3±0.4			

Table 4: Derived ZPD Locations (units: SMEC mirror position in µm), SSW array, Linear Phase Method

Tables 5 and 6 below show a selection of the ZPD positions as derived from the analysis carried out by Jean-Paul Baluteau[2].

[2] Ibid.

B		8200.3		8209.6	
C	8199.8		8208.9		8218.7
D		8208.3		8217.5	

Table 5: ZPD Locations (units: SMEC mirror position in μm), SLW array[3] (CBB Temperature = 7.5K)

F	E	D	C	B
	8199.5		8210.6	
8198.6		8209.4		8220.6
	8208.5		8219.4	

Table 6: ZPD Locations (units: SMEC mirror position in μm), SSW array[4] (CBB Temperature = 13K)

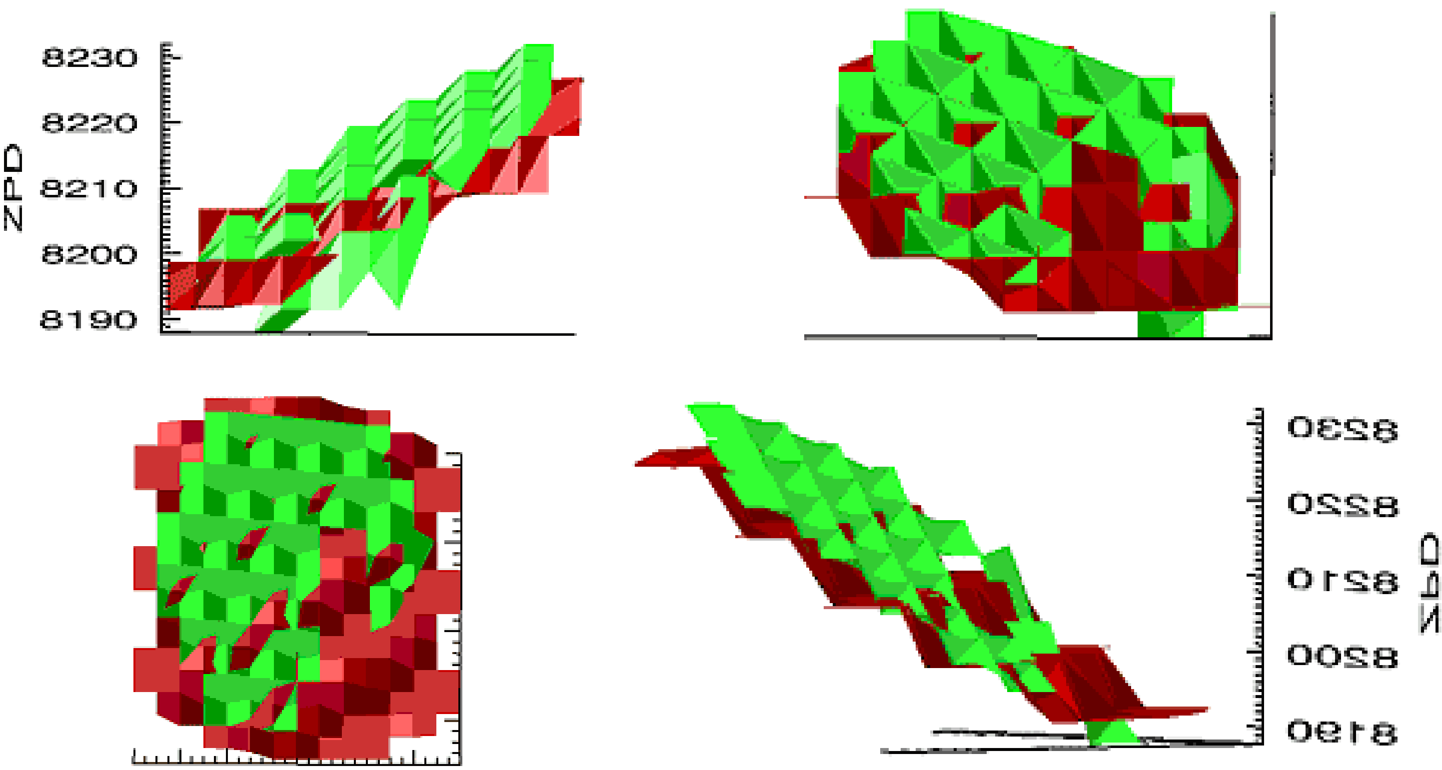

Figure 5: Surface plots of the distribution of the ZPD position. The plots shown are four different views of the distribution of derived ZPD positions (units: SMEC mirror position in μm) across the **SLW** and **SSW** arrays for the data set where the CBB was set to 7.5K.

4 Discussion

The plots shown in Figure 5 clearly indicate that not only is the observed position of ZPD not constant from pixel-to-pixel for each BDA, but that there is a trend in

[3] Ibid, page 6.
[4] Ibid, page 6.

the observed ZPD position. Of interest is the fact that this trend is linear in its nature rather than radial.

The most likely cause of this observed trend in the ZPD positions is a misalignment within the spectrometer. As shown in Figure 6, rays that are incident upon different portions of the detector array travel different distances (on average). Thus a slight deviation through an angle θ can result in an apparent shift in the ZPD position.

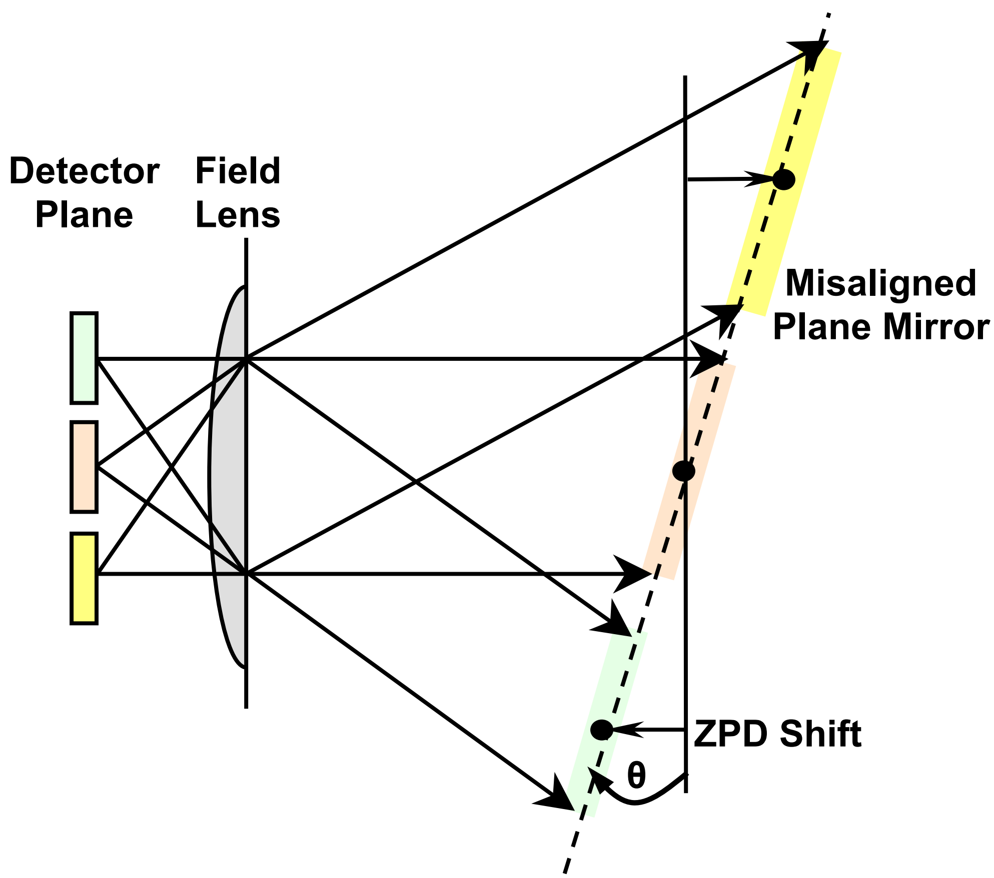

Figure 6: Possible effects of a spectrometer misalignment. The shaded areas correspond to the projection of the detector onto a plane mirror. The black circles represent the shifted ZPD positions for each of the detector pixels shown. (Figure not drawn to scale, misalignment exaggerated for clarity).

From the diagram shown in Figure 6, it is possible to estimate the shift in the position of zero path difference as a function of the misalignment angle, θ.

$$\tan(\theta) = \frac{\textbf{ZPD Shift}}{\textbf{Image Radius}} = \frac{\sim 20\mu m}{\sim 15000\mu m}$$

$$\theta \approx 0.1^{\circ}$$

5 Summary

As a first step in the analysis of the measured interferogram phase, we have attempted to determine the position of zero path difference for each of the spectrometer detectors. Previous work by Jean-Paul showed a variation in the ZPD positions across each spectrometer array (see Tables 5 and 6). The results of our study also showed a shift in the ZPD position across each BDA (see Tables 1-4, Figure 5).

The similarity of the ZPD shift between the two arrays (Figure 5) is an indication of a misalignment in the FTS. While we don't have sufficient details of the optical model of SPIRE to take this analysis much further, a quick calculation showed that a misalignment of the rooftop mirrors (or perhaps of the beamsplitters) of the order of a few tenths of a degree could explain the observed shift in the ZPD position. It would be interesting to see if Marc can use his model to predict the level of misalignment and if this confirms the suggested earlier misalignment proposed to explain the vignetting curves.