# SPIRE

## Determination of Optimum POF5 – Scan Map Parameters

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# Contents

## 1. Introduction

This document outlines a series of investigations aimed at determining the optimum observing parameters for the SPIRE scan-map observing mode (POF 5). The resulting derived parameters correspond to those outlined in the [1]; namely scan direction, scan-rate, and angular distance between scans. These parameters constitute the primary factors required for optimisation, with all remaining parameters being adjusted depending on the specific scientific case.

## 2. Summary of Results

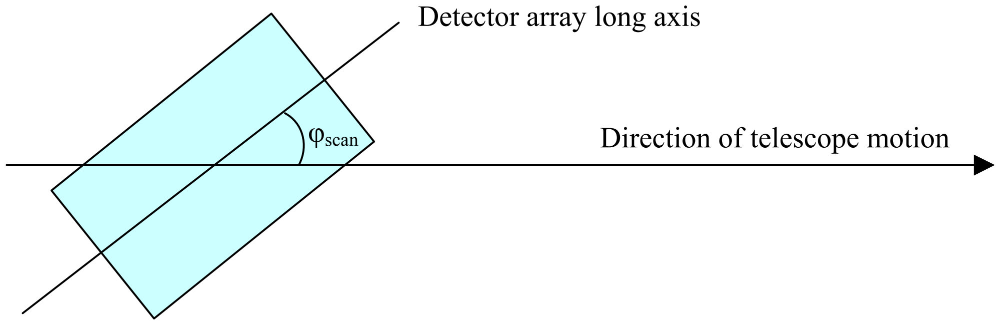
<table>
<tr><th rowspan="2">Optimised parameter</th><th colspan="3">Individual Band</th><th rowspan="2" colspan="3">3 band simultaneous operation</th></tr>
<tr><th>PSW</th><th>PMW</th><th>PLW</th></tr>
<tr><td>Scan angle (degrees)</td><td>12.4</td><td>12.4</td><td>12.4</td><td colspan="3">12.4</td></tr>
<tr><td>Angular line separation (arcsec)</td><td>235</td><td>243</td><td>258</td><td colspan="3">235</td></tr>
<tr><td>Scan-rate (arcsec/sec)</td><td>25</td><td>40</td><td>60</td><td colspan="3">25*</td></tr>
<tr><td>Time to map 1 sq. deg. (s) †</td><td>2572</td><td>1984</td><td>1670</td><td colspan="3">2572 (42 m 52 s)</td></tr>
<tr><td>Fraction of time on map</td><td>0.78</td><td>0.64</td><td>0.47</td><td colspan="3">0.78</td></tr>
<tr><td rowspan="2">5σ detection limit in 1 sq. deg. map (mJy)‡</td><td rowspan="2">65.4</td><td rowspan="2">97.9</td><td rowspan="2">124.9</td><td>PSW</td><td>PMW</td><td>PLW</td></tr>
<tr><td>65.4</td><td>76.5</td><td>80.7</td></tr>
</table>

- All bands within 2.5 % of optimum signal to noise loss factor.
† - Times include all overheads. See section below for overhead time estimation.
‡ - Values derived assuming a channel yield of 80 %, overall instrument efficiency of 80 %, and include signal to noise ratio loss factor (outlined below).

## 3. Optimum Scan Direction

The scan direction, $\varphi_{scan}$, also referred to as the scan angle, is defined as the angular separation between the detector array long axis (Y-axis in spacecraft coordinates) and the array's direction of motion (**Figure 1**).

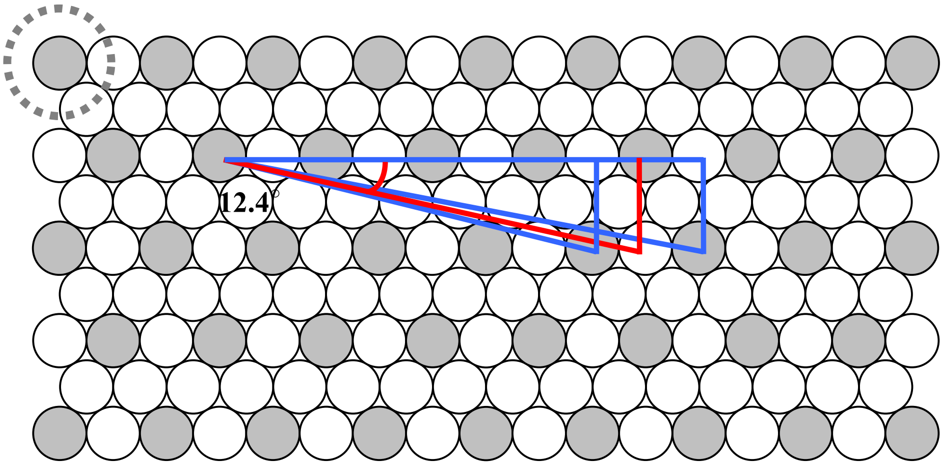
**Figure 1:** Illustration of scan direction parameter definition




Due to the SPIRE array's large number of pixels, it is possible to scan in a direction such that we achieve higher than Nyquist sampling, while still receiving information from multiple independent detectors within a single scan.

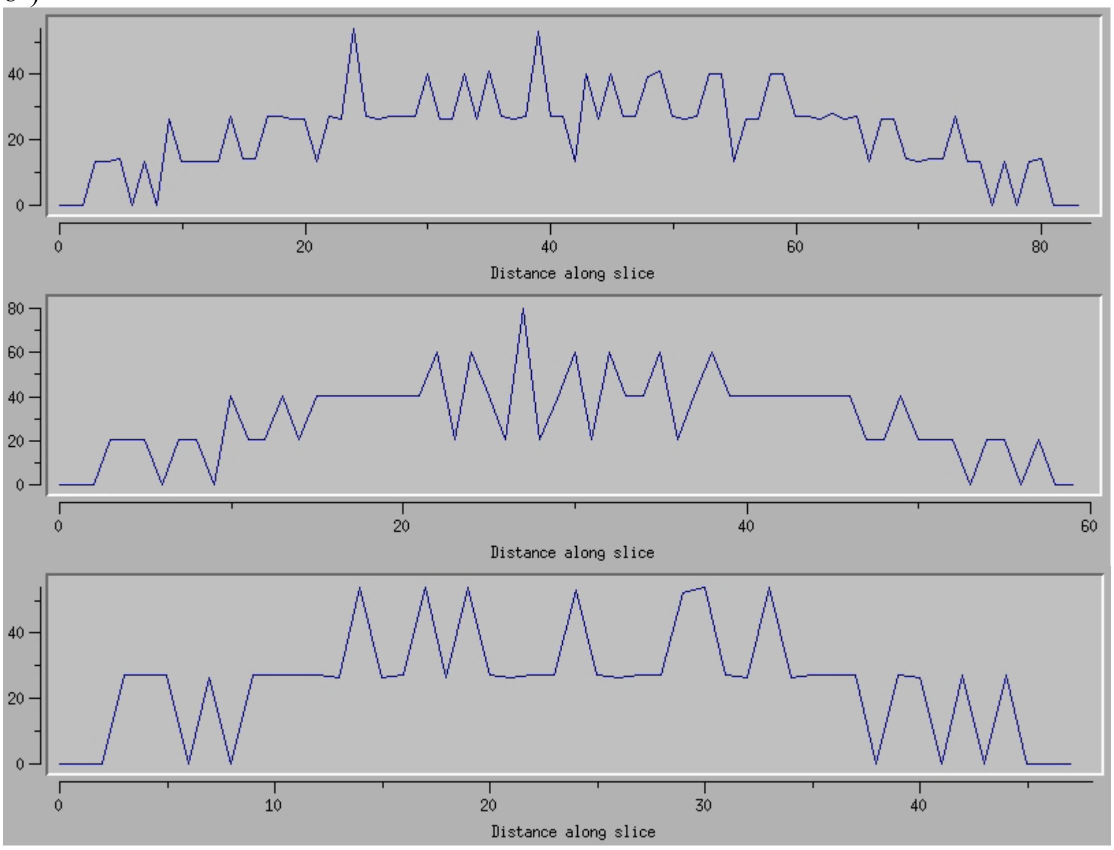
In order to achieve the highest possible spatial sampling, a direction is taken which ensures that a detector, as far as is possible, does not pass directly over another detector's central, or half width half maximum position, until a substantial fraction of an array distance has been travelled. The optimum direction found is 12.4°, derived as shown in **Figure 2**.

**Figure 2:** SPIRE PLW array projection on the sky - detectors displayed as grey circles, white circles act as spacers, all circles are equivalent to FWHM. Dotted circle represents the physical size of the feedhorn on the sky




This direction provides scan data sufficient to produce maps with half Nyquist sized map pixels. The high spatial sampling results in an increased uniformity in the map's signal to noise coverage (**Figure 3**). Such uniformity will be particularly important for the large-scale survey programs.

**Figure 3:** Single scan line cross-section. Schematic of integration time in a slice taken perpendicular to the telescope motion for a scan direction of 12.4 deg. Half Nyquist pixelisation (PSW - 4", PMW - 6", PLW - 8")

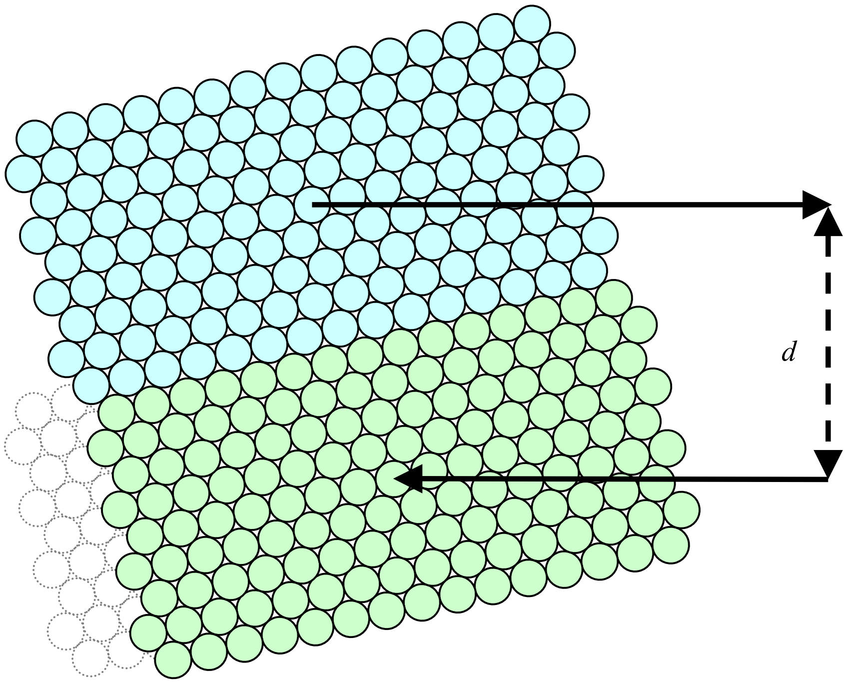


The 12.4° angle is preferential to the counterpart angle of 77.6° as it ensures multiple sampling of single regions with many different detectors. Also the high spatial sampling result only holds when scanning along the long axis, due to the larger number of detectors in this direction.

## 4. Optimum Angular Line Separation

The optimum angular line separation, *d*, is the distance between successive scan lines that ensures the map is equally uniform along, and perpendicular to, the scan line direction. In order to achieve this it is necessary to derive a separation which will allow each scan line to fit perfectly in to place with the previous line's observation, thereby creating a scan equivalent to one made with a single array with an effective size of *n* scan lines (see **Figure 4**).

**Figure 4:** Illustration showing the interlocking array structure arising from the optimum scan separation d. Also shown in shadow is the true end of scan position.



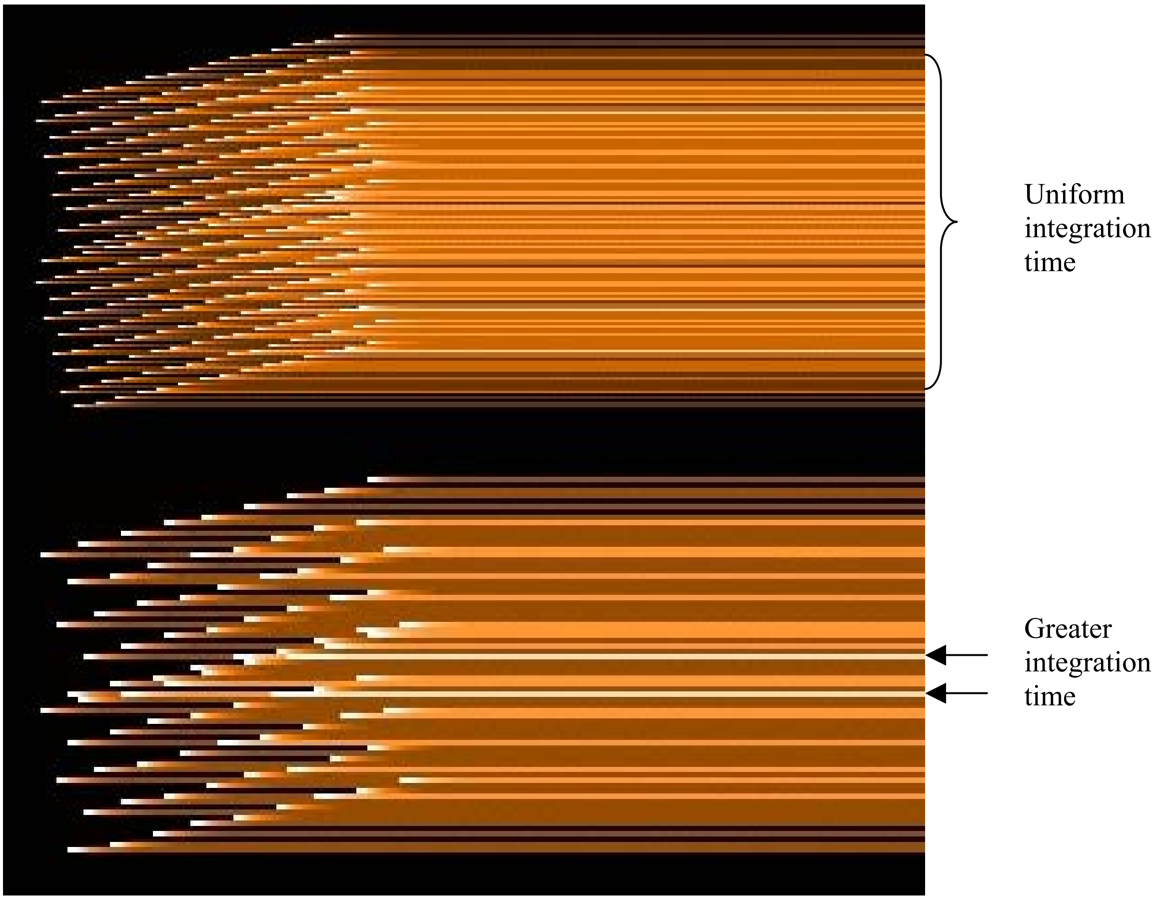

The optimum scan separation is also dependant on the particular array geometry, and hence is different for each array. The optimum value of *d* for a given scan direction is given by the following equation:

$$d = \frac{S}{2}\left(N\sqrt{3}\cos(\varphi_{scan}) - \sin(\varphi_{scan})\right),$$

where *S* is the bolometer separation on the sky in arc seconds ($S_{PSW}$ = 31.4, $S_{PMW}$ = 41.8, $S_{PLW}$ = 62.8), *N* is the number of bolometer rows making up each array ($N_{PSW}$ = 9, $N_{PMW}$ = 7, $N_{PLW}$ = 5), and $\varphi_{scan}$ is the scan direction. For a scan direction of 12.4° the resultant values of *d* are 235, 243, and 258 arcsec for the PSW, PMW, and PLW bands respectively. In order to ensure fully sampled maps in all bands an optimum separation of 235 arcsec, corresponding to the PSW optimum, has been chosen when observing in all three bands simultaneously. This does result in some loss in uniformity in the PMW and PLW, where the integration is slightly higher in the overlap region, however this is more favourable than the having unobserved regions in the PSW maps.

In addition to the sub-optimal spacing in the PMW and PLW, there also exits a slight non-uniformity due to the variation in the make up of the different arrays. The pixels found at the corners of the PMW and PLW arrays do not have counterparts in the PSW. Consequently there is a slight increase in integration time near the overlap, where there is an increase in the total number of detectors observing a single line. This can be seen in **Figure 5**.

**Figure 5:** Integration time maps showing two line scans in the PSW (top), and the PLW (bottom) bands




## 5. Optimum Scan Rate

Optimisation of the scan rate parameter, $\dot{\theta}$ is dependant on two instrument systematics, the 1/*f* noise knee frequency, and the on-board 5 Hz analogue filter. The losses resulting from these systematics vary contrary to one another. As a result there will be an optimum scan rate such that the net losses are minimised. A high scan rate reduces the effect of 1/*f* noise, but a slow rate reduces the effect of the filter.

The total signal to noise loss factor can be considered to be the product of the losses arising from the 5 Hz filter, and 1/*f* noise effects, i.e.:

$$loss_{total}(\dot{\theta}, f_{knee}, FWHM) = loss_{filter}(\dot{\theta}, FWHM) \times loss_{1/f}(\dot{\theta}, f_{knee}, FWHM)$$

Using a beam crossing time $\tau_{beam}$, defined as the time to scan an angular distance of two FWHM,

$$\tau_{beam} = \frac{2 \times FWHM}{\dot{\theta}},$$

and the measured filter response function, it is possible to determine the signal to noise ratio loss as a function of scan rate for a given FWHM.

Data relating to the signal to noise loss as a function of 1/*f* knee frequency is also available (see Appendix).

Due to the inverse relationship between $\dot{\theta}$ and observed $f_{knee}$ it sensible to combine these two parameters into a single new variable representing the effective 1/*f* variation seen in the final data. This parameter will hence be referred to as $f_{data}$, and is defined mathematically as:

$$f_{data} = f_{knee} \times \tau_{beam}$$

Using these data it is now possible to generate a function to relate signal to noise ratio loss factor as a function of $\dot{\theta}$ for a given $f_{knee}$ (**Figure 6**).

**Figure 6:** Total signal to noise ratio loss factor as a function of scan rate for the PSW (red), PMW (green), PLW (black), and combined bands (blue), for a 1/f noise knee of 100 mHz.

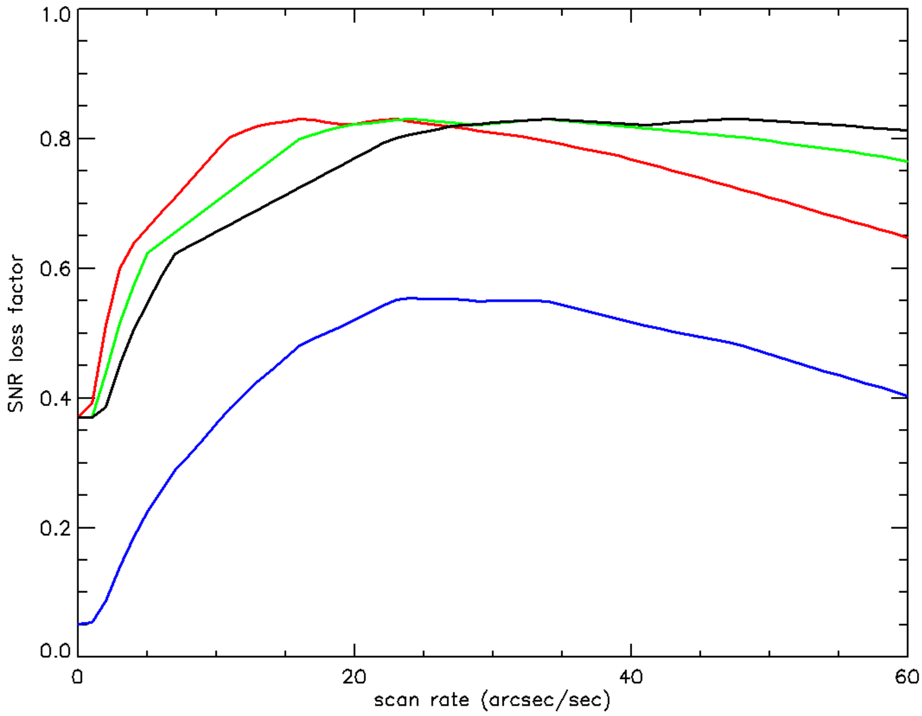
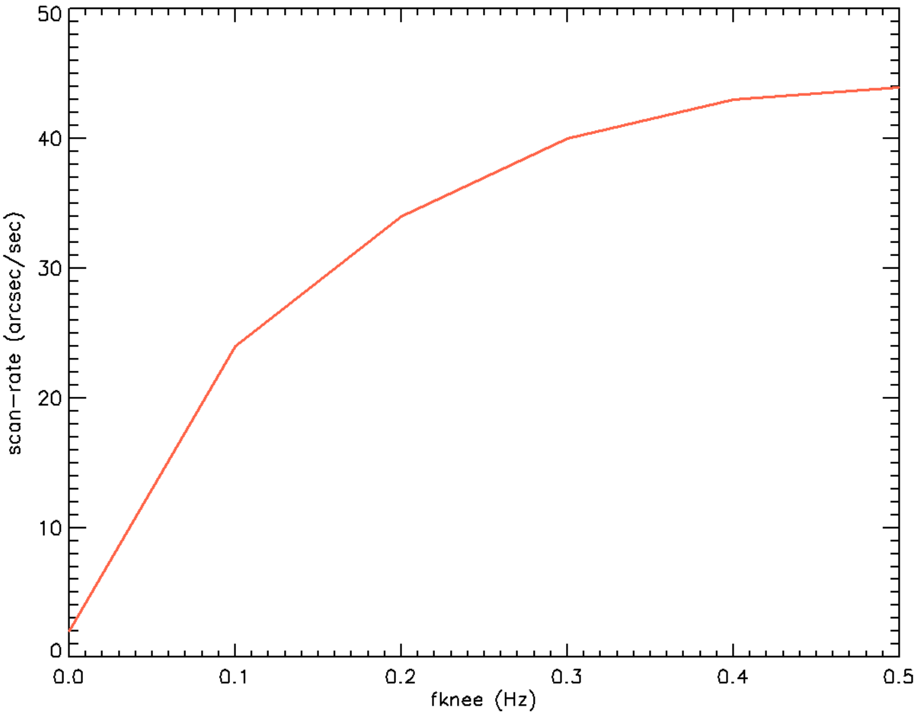



**Figure 6** shows the signal to noise ratio loss factor, for a specific value of $f_{knee}$, in all three SPIRE bands. These plots take in to account the two systematic effects described above, and give optimum values of $\dot{\theta}$ for the PSW, PMW, and PLW of **25**, **40**, and **60 arcsec/sec** respectively.

The fourth blue curve is the product of all three bands. As a result, the peak of this curve reveals the optimum value of $\dot{\theta}$ when observing in all three bands. This gives an optimum scan-rate of approximately 25 arcsec/sec resulting in signal to noise ratio losses factors of 0.82, 0.83, and 0.81 in the PSW, PMW, and PLW bands respectively. Operationally however it is possible to scan at rates between 20 – 35 arcsec/sec without any significant degradation in performance. All values are correct assuming a nominal fknee of 100 mHz.

Optimum scanning rates vary with knee frequency as shown in **Figure 7**. An optimum scan-rate maximum of approximately 40 arcsec/sec is reached near a knee frequency of 0.5 Hz. High values of 1/f require a high scanning speed but the 5 Hz filter becomes more important and acts to suppress the signal to noise, particularly in the PSW band. Therefore, high scanning rates can never be considered optimum when scanning in all three bands.

**Figure 7:** Optimum scanning rate as a function of $f_{knee}$




## 6. Consequences of Optimised Parameters On Sample Scan

Using the optimised observing parameters defined above, the times taken to map a 1 sq. deg. field have been computed. These times include an estimated telescope turn around time. Turn around times are calculated assuming a constant and instantaneously acting acceleration / deceleration of 3 arcsec / $s^2$, and a square turn around. An extra 20 % is also added to the turn around times to account for the time required to perform a pointing calibration. 14 scan lines are required to complete a minimum of 1 sq. deg. in all cases other than optimum mapping in the PLW, which requires 13 lines.

Using these values, along with $\Delta S_{5\sigma\_1hr}$ limiting flux sensitivity values for each band and on source integration times, derived in [2], we are able to derive a 5σ limiting flux density for these 1 sq. deg. maps. Also included at this point is a predicted channel yield of 80 %, an overall instrument efficiency factor of 80 %, and the observed signal to noise ratio loss factor as appropriate for the parameters used and a nominal $f_{knee}$ of 100 mHz. Results for these sample maps are contained in the table below.

| | Individual bands - own optimisation | | | All bands simultaneously – system optimisation | | |
|---|---|---|---|---|---|---|
| | PSW | PMW | PLW | PSW | PMW | PLW |
| Observation time (s) | 2572 | 1984 | 1670 | 2572 | | |
| Fraction of time on map | 0.78 | 0.64 | 0.47 | 0.81 | | |
| Limiting 5σ flux (mJy) | 64.5 | 97.9 | 124.9 | 65.4 | 76.5 | 80.7 |

## 7. References


[1] Griffin, M., Swinyard, B., King, K., *Operating modes for the SPIRE instrument, Issue 3.3*, SPIRE-RAL-DOC-000320, 2005

[2] Waskett, T., Sibthorpe, B., *SPIRE Photometer Simulator Verification – Scan Map Sensitivity*, Cardiff University internal document, SPIRE-UCF-NOT-002756, 2005

## 8. Appendix

Data used to calculate signal to noise ratio loss factors required to derive the optimum scan-rate.

**Figure 8:** Signal to noise ratio loss factor as a function of fknee

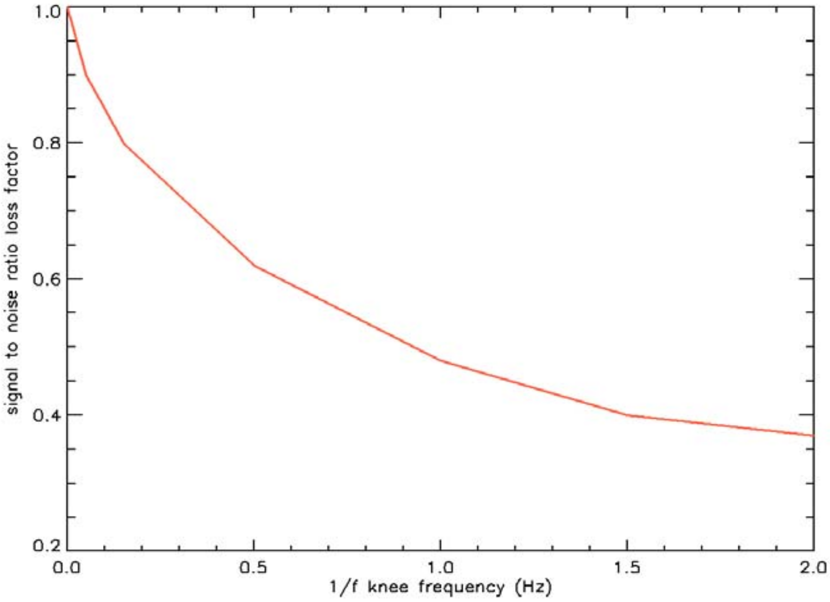



**Figure 9:** 5 Hz filter response profile