Change Note

Issue 1: 30/11/1999	Issued for Warm electronics PDR including all detector options
Issue 2: 26/04/2000	Updated to remove all detector options except feedhorns and to reflect new subsystem block diagram and extra BSM failure mode
Issue 3: 23/11/2000	Updated for System Review and to reflect revised thinking on instrument observing modes.

Introduction

This note attempts to outline the systems level criticality of the failure, or partial failure, of one or more of the SPIRE cold FPU sub-systems. There is no distinction made in this discussion of where the failure might occur: that is it could be mechanical failure of the cold system; a failure in the wiring harness or a failure in the control electronics or software. This note does not discuss the likelihood of any sub-system failing, only the scientific and operational consequences of the failure with a view to identifying the mission critical sub-systems and failure modes that must be addressed in the design of the sub-system and its drive electronics. For the purposes of this note, the SPIRE sub-systems are as shown in figure 1

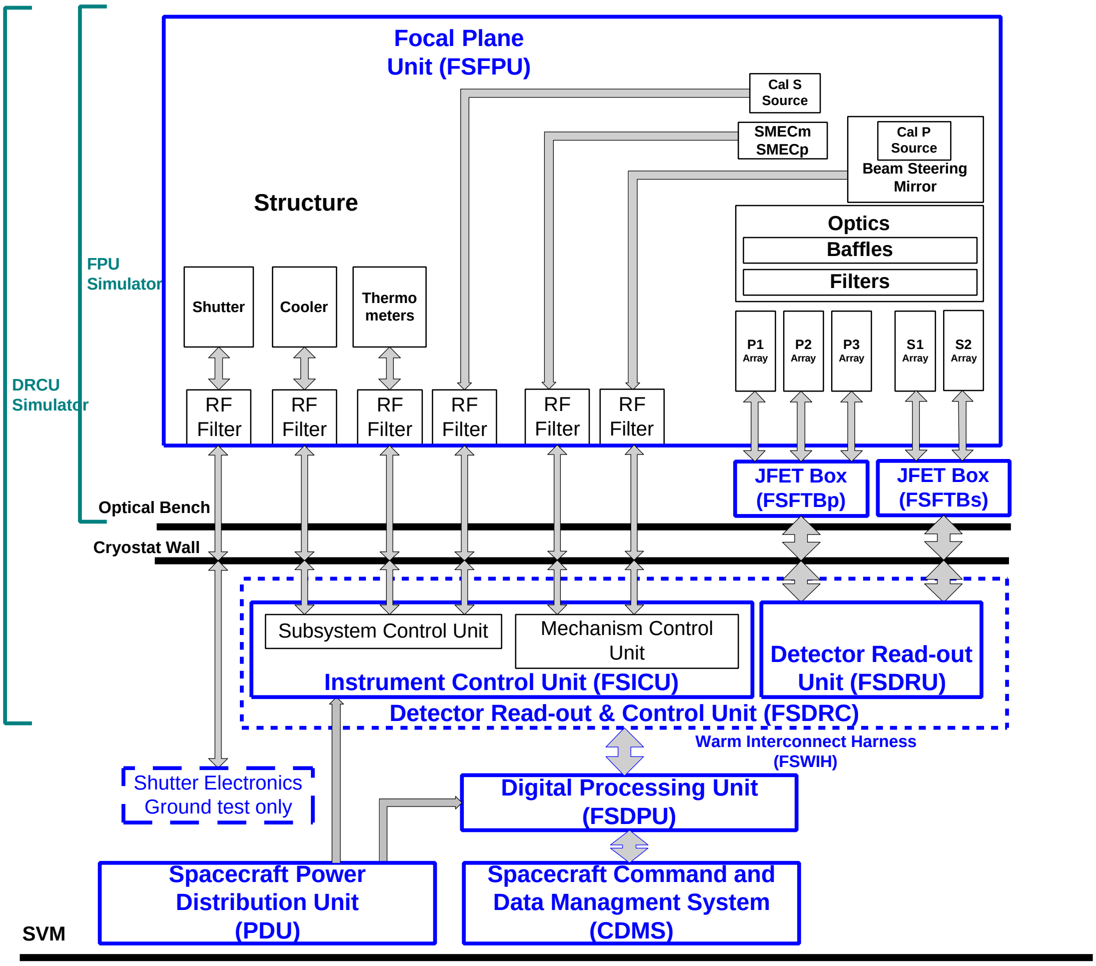

Figure 1: Schematic Representation of the SPIRE sub-systems

Sub-system Criticality

Sub-system	**Failure mode**	**Consequence**	**Remedial Action**	**System Level Redundancy**
1. Cooler	**a.** Loss of ^{3}He cooling	Total loss of instrument	None	None
	b. Partial loss of ^{3}He cooling (ineffective or inefficient recycling; abnormal thermal load at 300 mK etc etc)	Possible operational constraints if large impact on lifetime.	Load on 300 mK is essentially all parasitic. The only remedial action is to recycle the cooler more often and, if mission lifetime is to be maintained, to use SPIRE less frequently.	Fully flexible operations.
2. Photometer Arrays	**a.** Total loss of short wavelength array	Simultaneous three band photometry lost Mapping of large regions in three bands will be impossible. The same science can be done using PACS LW band but survey will take longer. Point source photometry possible using spectrometer but with much reduced sensitivity	Use spectrometer for point source photometry	PACS LW band
	b. Total loss of medium wavelength array	Simultaneous three band photometry lost Mapping of large regions in three bands will be impossible. The same science can be done using SW and LW bands but with reduced fidelity. Point source photometry possible using spectrometer but with much reduced sensitivity	Ditto	None necessary
	c. Total loss of long wavelength array	Long wavelength photometry mapping lost for whole of FIRST	Ditto	None

Sub-system	**Failure mode**	**Consequence**	**Remedial Action**	**System Level Redundancy**
	d. One pixel fails	Some point source photometry possible using spectrometer but with very poor sensitivity Slight increase in jiggle chop mode complexity to achieve fully sampled FOV Small loss in scan mode sensitivity If the pixel lost is one of the four “prime” pixels then another will have to be used for setting up the pointing of the observations (see note 2) If one of the prime pixels is lost then observations using satellite nodding are less efficiently carried out.	Use BSM to fill in for missing pixel if required by observation.	Four “prime” pixels in each array – redundant as two pairs? (see note 2)
	e. One row or column of pixels fails	More complex jiggle/chop mode required to achieve fully sampled FOV Small loss in scan mapping ability	Use BSM to “fill in” missing row or column in jiggle/chop mode Always scan “across” missing row or column in scan mode	Many columns; not so many rows (see note 2)
	f. One block fails	Depending on the size of the block will have to use up to full chop throw of BSM to recover fully sampled FOV. If block is greater than 2 arcmin then will need to use satellite Scan mode suffers a greater loss in sensitivity	Use BSM to “fill in” missing block if less than 2 arcmin Use satellite and BSM together if greater than 2 arcmin	In principle as many “blocks” as rows? (see note 2)
3. Spectrometer Arrays	**a.** Loss of short wavelength array	Total loss of low/medium resolution spectroscopy on FIRST in 200-300 micron waveband	None	HIFI may cover this range at much higher spectral

Sub-system	**Failure mode**	**Consequence**	**Remedial Action**	**System Level Redundancy**
				resolution
	b. Loss of long wavelength array	Total loss of low/medium resolution spectroscopy on FIRST in 300-400 micron waveband	None	HIFI will cover this range at much higher spectral resolution
	c. Loss of any one pixel	If centre pixel then will have to nominate off axis pixel as “prime”. Possible loss of sensitivity and spectral resolution using off-axis pixel Obtaining a fully sampled image will be more difficult.	Offset pointing of satellite from on-axis beam More complicated jiggle mode BSM operation to fill in for missing pixel.	Many pixels. (see note 3)
	d. Loss of any block of pixels	If whole array is a single block then total loss of this channel – LW channel is particularly vulnerable here. Very difficult/slow to obtain fully sampled image.	Offset pointing of satellite from on-axis beam Nod satellite to fill in missing block for mapping.	Two blocks in SW array – only one for LW array.
4. Beam Steering Mechanism	**a.** Total loss	All jiggle/chop modes lost No modulation of signal in pointed modes – must use bias modulation Full sampling of FOV in photometer only possible in scan mode Full sampling of FOV is not possible in spectrometer Partial recovery of spatial sampling possible using satellite fine raster - slow	Use scan mode for full sampling of FOV Satellite nodding must be used to remove any telescope temperature drift and to replace chopping for extended sources Satellite fine raster mapping could be used to partially recover sampling for feedhorn arrays	Two axes in BSM – total failure less likely Bias modulation is implemented. Satellite operations

Sub-system	Failure mode	Consequence	Remedial Action	System Level Redundancy
		Photometry of extended sources will be difficult without chop – use satellite instead with loss in efficiency due to overheads		
	b. Mirror stuck at extreme chop position	If the mirror fails at its extreme chop position in the +Y direction and cannot be recovered there will be a loss of part of the photometer FOV. If it fails in the extreme –Y direction there will be vignetting of the spectrometer FOV.	Use unvignetted portion of array with loss of efficiency.	Electrical failure can be avoided by design. Mechanical failure might be avoided by design. A launch lock must be fitted to prevent extremes of movement.
	c. Loss of chop axis operation	Pixel chopping still possible although not simultaneously in all bands. Large angle chopping lost Full sampling of FOV in photometer only possible using scanning or raster mode of satellite with loss of efficiency. Full sampling of FOV in spectrometer mode must be done using satellite in raster mode with loss of efficiency. Photometry of extended sources will be difficult without chop – use satellite instead with loss in efficiency due to overheads	Satellite nodding must be used to remove any telescope temperature drift and to replace chopping for extended sources Satellite scanning and raster must be used to achieve full sampling of FOV.	Satellite operations

Sub-system	**Failure mode**	**Consequence**	**Remedial Action**	**System Level Redundancy**
	d. Loss of jiggle axis operation	Full sampling of FOV in photometer only possible using scanning or raster mode of satellite with loss of efficiency. Full sampling of FOV in spectrometer mode must be done using satellite in raster mode with loss of efficiency. Any mechanical crosstalk between axes cannot be compensated for – possible loss of chopping efficiency	Satellite scanning and raster must be used to achieve full sampling of FOV.	Satellite operations
	e. Partial failure: High dissipation; sticking; restricted range of movement etc	Reduction in use of chopper Slower chop rate Increased systematic noise Increase in straylight from higher temperature motor	Change method and/or frequency of operation; slow the chop down or, in extremis, go to only scan mode to modulate signal	Flexible operations – well defined backup modes
	f. Loss of one or more position sensors	Chop mode may still be possible Jiggle mode is almost certainly lost as accuracy of mirror positioning is very uncertain	Use BSM open loop by commanding the current to the actuators Stabilisation of the mirror position is not guaranteed and this may not work!	Well defined backup mode
5. FTS Mirror Mechanism (SMECm)	**a.** Total loss	Loss of all low /medium resolution spectroscopy on FIRST	None	HIFI covers part of wavelength range at much higher spectral resolution
	b. Partial failure: High dissipation; sticking; restricted range	Reduction in use of spectrometer Loss of higher spectral resolution Increased systematic noise	Change method and/or frequency of operation; slow mirrors down or, in extremis, go to step and integrate	Flexible operations – well defined backup modes

Sub-system	**Failure mode**	**Consequence**	**Remedial Action**	**System Level Redundancy**
	of movement; etc	Increase in straylight from higher temperature motor	using BSM to modulate signal	
6. FTS mirror position sensor (SMECp)	**a.** Total loss	Inability to accurately know where the mirrors are or correct velocity Increase in systematic noise	Use motor current to reconstruct mirror position for rapid scanning Use motor current commanding to go to fixed positions and go to step and integrate using BSM to modulate signal	Ditto
	b. Partial loss – loss in signal or loss of one or more detectors	More noise on mirror position - may prevent accurate velocity correction Increase in systematic noise	Slow mirrors down	Ditto
7. Photometer calibrator	**a.** Total loss	Inability to monitor drift in detector responsivity Calibration may be slower leading to possible loss in instrument efficiency	Set up network of secondary astronomical calibration sources over as much of sky as possible.	Secondary astronomical calibrators identified before launch
	b. Partial failure – loss in output or frequency response; higher than expected dissipation etc	Possible loss in accuracy of any detector responsivity drift Make take longer to calibrate thus reducing instrument efficiency	Reduce number of calibration operations Reduce operating frequency – in extremis use as DC source with detector bias modulation. Reduce temperature of operation	Flexible operations – well defined backup modes
8. Spectrometer calibrator	**a.** Total loss	No compensation for telescope background Increased systematic noise on low resolution spectra Dynamic range limit hit on	Sufficient dynamic range in electronics to cope with uncompensated signal. Methods to reduce data rate will be	Flexible operations – well defined backup modes Secondary

Sub-system	**Failure mode**	**Consequence**	**Remedial Action**	**System Level Redundancy**
		amplifiers/digitisation Loss of automatic absolute calibration – calibration will be slower leading to loss in instrument efficiency	required as will now need 16 bits to encode detector signals around ZPD Slow down mirrors Take only data from centre detectors In extremis go to step and integrate using BSM to modulate signal. Use of secondary astronomical calibration sources.	calibrators identified before launch
	b. Partial failure – loss in output; higher than expected dissipation etc	Not possible to compensate properly across whole wavelength range Increased systematic noise on low resolution spectra	Run source at a lower temperature; use the spectrometer less often.	Flexible operations - well defined backup modes.
9. Thermometers and thermal control system	**a.** Loss of one or more structure; mechanism or warm electronics thermometers	No real impact in flight – behaviour of cold instrument well known from ground test One exception is that loss of some thermometers may cause problems with diagnosis of any problems	Use nearest neighbour	Many thermometers more important ones will have full redundancy

Table 1: Criticality analysis for the SPIRE cold FPU sub-systems.

Notes:

1. Use of Spectrometer to cover for Photometer point source spectroscopy

The spectrometer will have about half the throughput of the photometer over the 200-300 µm band and the 300-400 µm band. Its performance above 400 µm is not guaranteed and we should not rely on it for redundancy purposes. Chopping is possible in spectrometer mode but pixel swapping is not available therefore there will be a further loss in sensitivity.

2. Failures in photometer feedhorn arrays

As shown in figure 5, if the three arrays have central wavelengths of 250, 333 and 500 µm then there will be four co-aligned pixels along the central long axis of the arrays. Any one of these four positions can be used as the prime detector for placing a point source on the array for simultaneous observations in all four bands. It makes the chopped observations easier if the source can be swapped from one prime position to another so these should be counted as two pairs for redundancy purposes.

When the satellite is nodded one pixel of the alternate pair is used – see figure 4. If either of the central two prime detector locations suffers a failure then nodded observations will be much less efficient as several non/chop positions will be need to make up for the loss of the co-aligned pixels across the three arrays.

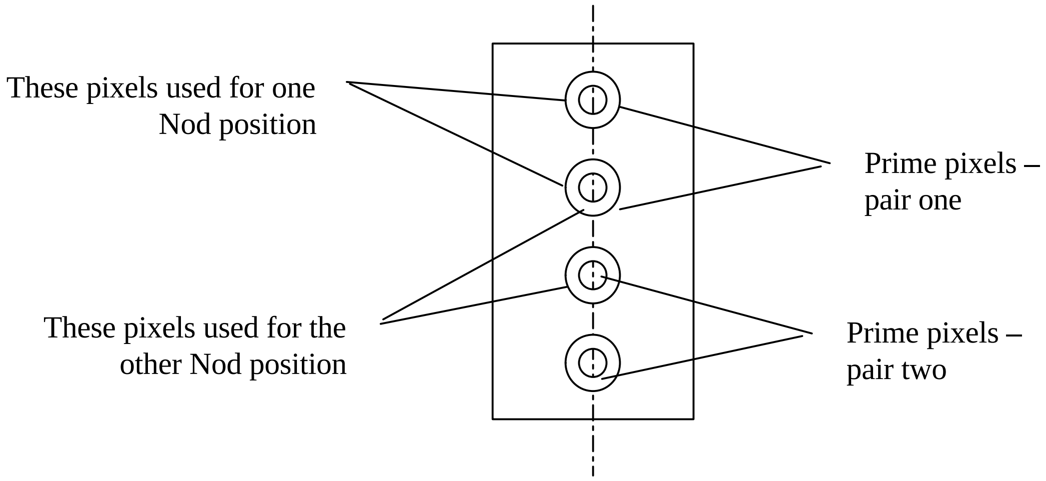

Figure 4: Sketch showing arrangement of co-aligned “prime” pixels on feedhorn arrays. The source is chopped from one of the pixels in a pair to the other. When the satellite is nodded one pixel of the other pair is used.

3. Failures in spectrometer feedhorn arrays

The feedhorn arrays for the spectrometer will be hexagonally close packed with 37 detectors for the short-wavelength (central wavelength 250 µm) array and 19 detectors for the long-wavelength (central wavelength 350 µm) array – see figure 5. The outer edges of each array will likely suffer from reduced performance due to vignetting – the outer ring of pixels in each array is therefore not to be considered for redundancy purposes. The disadvantage of the present baseline arrangement for the spectrometer is that there is only one common pixel between the wtwo arrays. This leaves the spectrometer vulnerable to large loss in oberving efficiency in the event of loss of one or other pixel.

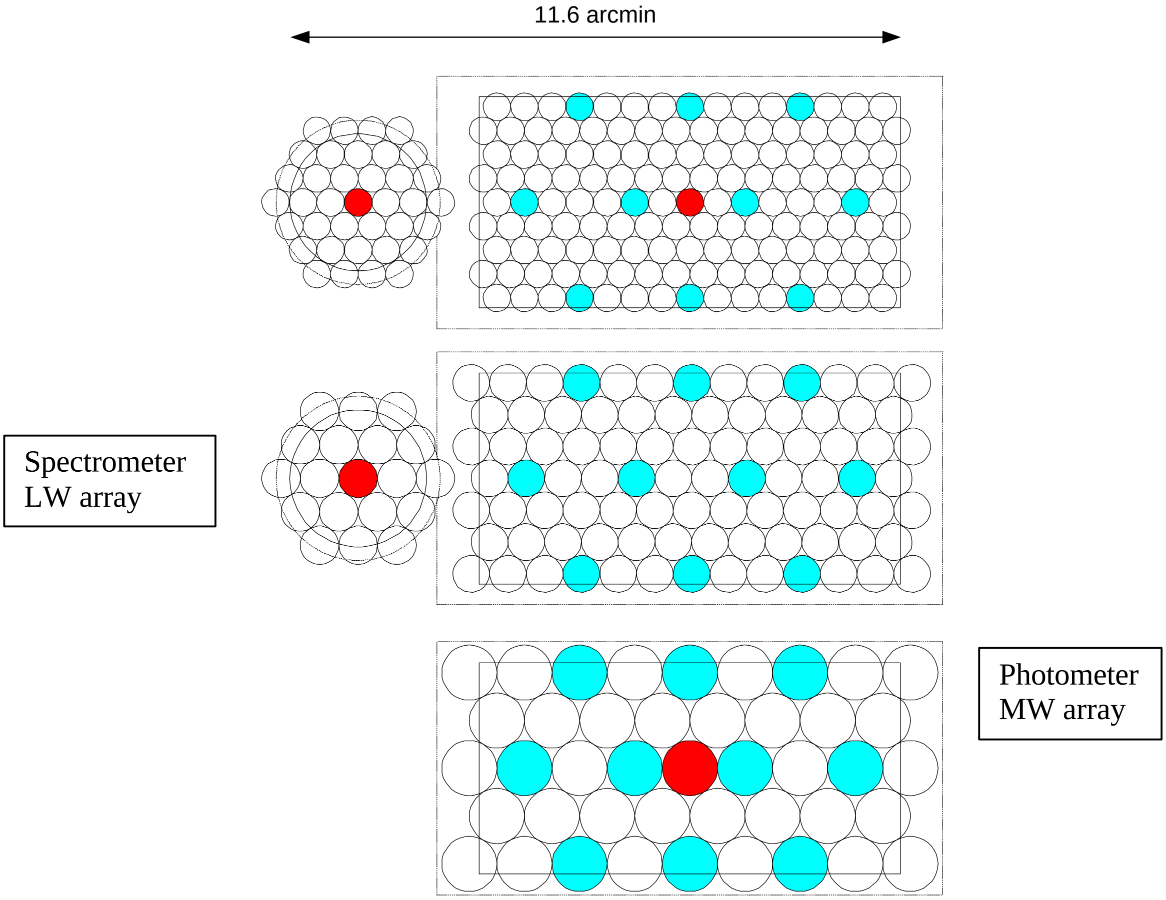

Figure 7: Proposed layout of the photometer and spectrometer focal planes. The geometric FOV in each case is shown as the solid black line – the dashed line is the conanical 20% overised FOV that will allow for any diffraction. The instrument optics will allow the over sized FOV onto the sky albeit with some vignetting at the edges. The red pixels are aligned with the instrument boresight for each channel the blue pixels view the same point on the sky.

An alternative arrangement is proposed in figure 6. Here the diameter of the short wavelength feedhorns is reduced to 2.25 mm thus fitting them better to the FOV, and the diameter of the long wavelength feedhorns is set at 2x2.25xcos(30)=3.8971 mm. If the long wavelength array is then rotated by 30^o w.r.t. to the short wavelength we end up with 13 overlapping pixels. This makes the spectrometer observations more efficient and removes the dependency on only the central pixel.

It remains to be seen whether there is any significant performance loss from having the feedhorns with these diameters.

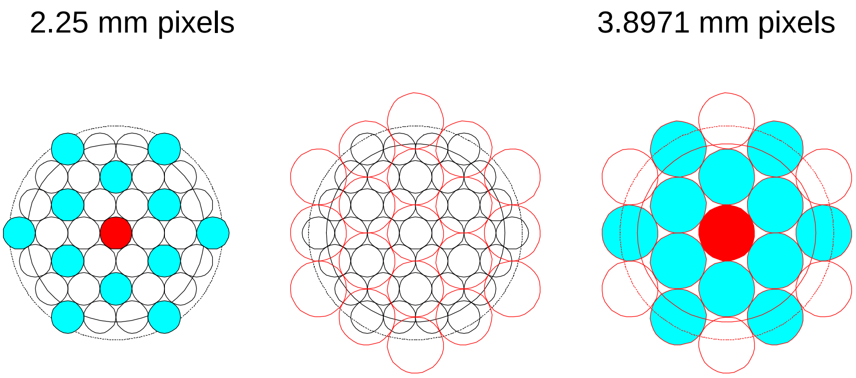

Figure 5: Proposed alternative arrangement for the spectrometer feedhorn arrays. This arrangement provides 7 overlapping pixels within the geometric FOV and 13 overlapping pixels total.

Conclusions

The mission critical failures are those in the table where there are no straightforward system level redundancies – i.e. where "None" appears in the **Remedial Action** and/or **System Level Redundancy** columns. To summarise these are:

- ☐ Total loss of the cooler
- ☐ Total loss of the photometer long wavelength array
- ☐ Total loss of either spectrometer array
- ☐ Total loss of the FTS mirror mechanism

All other failures will lead to a greater or lesser degree of loss of performance and difficulty of operation, but they do not lead to a total failure of either the photometer or spectrometer scientific goals. The redundancy and reliability of these sub-systems must be addressed as a first priority.

The following recommendations can also be made from the analysis of the array failure criticality discussed here.

1. The photometer feedhorn arrays should preferably be arranged as rows as this gives maximum redundancy; i.e. sharing of control lines; amplifiers; ADC's etc, in rows rather than columns. Especial care must be taken over the reliability of the inner two prime pixels in each array as the loss of any one of these across the three arrays would cause a loss in operational efficiency.

2. With the baseline pixel arrangement, the loss of the central pixel of the spectrometer feedhorn arrays will cause a lot of difficulty in the operation of the spectrometer. Consideration should be given to the proposed alternative arrangement of the spectrometer feedhorn pixels to provide redundancy.

3. The possibility exists of the BSM getting stuck in its extreme chop position. Consideration should be given to a launch lock or other mechanical design to prevent a mechanical failure of this type.

The following instrument backup operating modes are required in event of sub-system or system failure:

1. More frequent cooler recycling including the possibility of autonomous recycling under control of the DPU alone.
2. Slow chop mode in the event of partial BSM failure
3. Open loop BSM control using commanded current to the actuators
4. Single axis BSM operation
5. Slow scanning of FTS mirrors
6. Step and look operation of the FTS in conjunction with the BSM
7. Open loop operation of the FTS mechanism by commanding the current to the actuator
8. DC operation of photometer calibrator – V-I's on detectors under different loadings for calibration?
9. Selection of smaller numbers of detectors from photometer arrays in event of telemetry bandwidth problems
10. Selection of smaller number of spectrometer detectors in event of problems with telemetry bandwidth and/or loss of spectrometer calibrator