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.
Issue 4: 4/04.2001	Addition of treatment of 300 mK "system" as a potential catastrophic failure Changes to detector discussion to reflect real way the detector wiring will be instigated JFET units considered separately to the BDAs to reflect possibility of switching down individual units.

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

An additional "system" is discussed here which is the 300 mK architecture that is cooled by the sorption cooler. For the purposes of the discussion here it consists of all the "kevlar" suspended items from the cold tip to the bolometer detector arrays themselves. There are three separate items here: the evaporator – which is effectively part of the cooler – the cold strap or busbars and the suspended section of the detectors. A failure in any part of this system could result in a thermal short to 300 mK and, therefore, the inability to continue cold operation of the instrument. It is therefore treated as a major possible failure mode for the instrument.

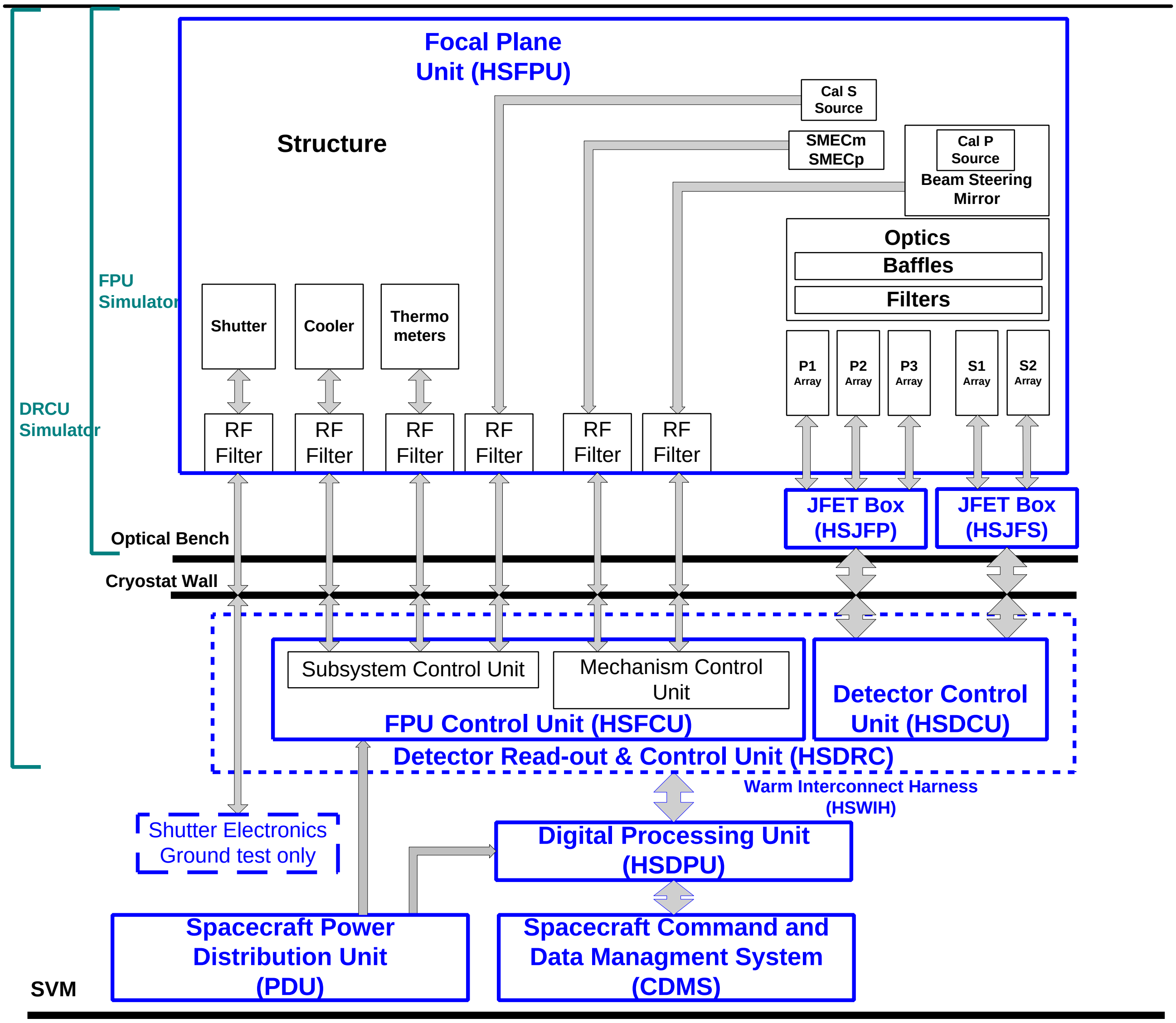

Figure 1: Schematic Representation of the SPIRE sub-systems

Sub-system Criticality

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

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. 300 mK system	**a.** Structural failure leading to thermal short to 1.7 or 4 K	Total loss of instrument	None	Multiple structural elements – "soft" failure modes designed into 300 mK structure to prevent hard thermal contacts.
	b. Structural failure leading to increased conduction into 300 mK level.	Possible operational constraints if large impact on lifetime.	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
3. 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	Use spectrometer for point source photometry	PACS LW band

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

Sub-system	Failure mode	Consequence	Remedial Action	System Level Redundancy
		spectrometer but with much reduced sensitivity		
	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 Some point source photometry possible using spectrometer but with very poor sensitivity	Ditto	None
	d. One pixel fails	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 block fails	Depending on the size of the block will have	Use BSM to “fill in” missing block if	Many blocks

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Sub-system	Failure mode	Consequence	Remedial Action	System Level Redundancy
		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 loss in sensitivity	less than 2 arcmin Use satellite and BSM together if greater than 2 arcmin	within each detector array as rows Arrangement of blocks within arrays is TBD.
4. 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 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	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.

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Sub-system	Failure mode	Consequence	Remedial Action	System Level Redundancy
		image.		
5. JFET Units	**a.** Excess heat load from single JFET unit due to electrical or mechanical failure	May cause the Herschel optical bench to be warmer than nominal – this may prevent efficient operation of the SPIRE instrument (or operation at all)	Ability to switch off power to individual JFET units or groups of units to ensure partial operation of spectrometer or photometer can continue.	Many JFET units
6. 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 Photometry of extended sources will be difficult without chop – use satellite instead with loss in efficiency due to overheads	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
	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 a large vignetting of the spectrometer	Use unvignetted portion of array with loss of efficiency. None for vignetted spectrometer FOV	Electrical failure can be avoided by design. Mechanical failure might be avoided by design. A

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		FOV.		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
	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:	Reduction in use of chopper	Change method and/or frequency of	Flexible operations

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

Sub-system	**Failure mode**	**Consequence**	**Remedial Action**	**System Level Redundancy**
	High dissipation; sticking; restricted range of movement etc	Slower chop rate Increased systematic noise Increase in straylight from higher temperature motor	operation; slow the chop down or, in extremis, go to only scan mode to modulate signal	– 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
7. 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 of movement; etc	Reduction in use of spectrometer Loss of higher spectral resolution Increased systematic noise Increase in straylight from higher temperature motor	Change method and/or frequency of operation; slow mirrors down or, in extremis, go to step and integrate using BSM to modulate signal	Flexible operations – well defined backup modes
8. 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

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Sub-system	**Failure mode**	**Consequence**	**Remedial Action**	**System Level Redundancy**
	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
9. 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
10. Spectrometer calibrator	**a.** Total loss	No compensation for telescope background Increased systematic noise on low resolution spectra Dynamic range limit hit on amplifiers/digitisation Loss of automatic absolute calibration – calibration will be slower leading to loss in instrument efficiency	Sufficient dynamic range in electronics to cope with uncompensated signal. Methods to reduce data rate will be 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	Flexible operations – well defined backup modes Secondary calibrators identified before launch

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Sub-system	Failure mode	Consequence	Remedial Action	System Level Redundancy
			calibration sources.	
	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.
11. 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

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.

2. Redundancy in the photometer feedhorn arrays

As shown in figure 3, 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 2. 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.

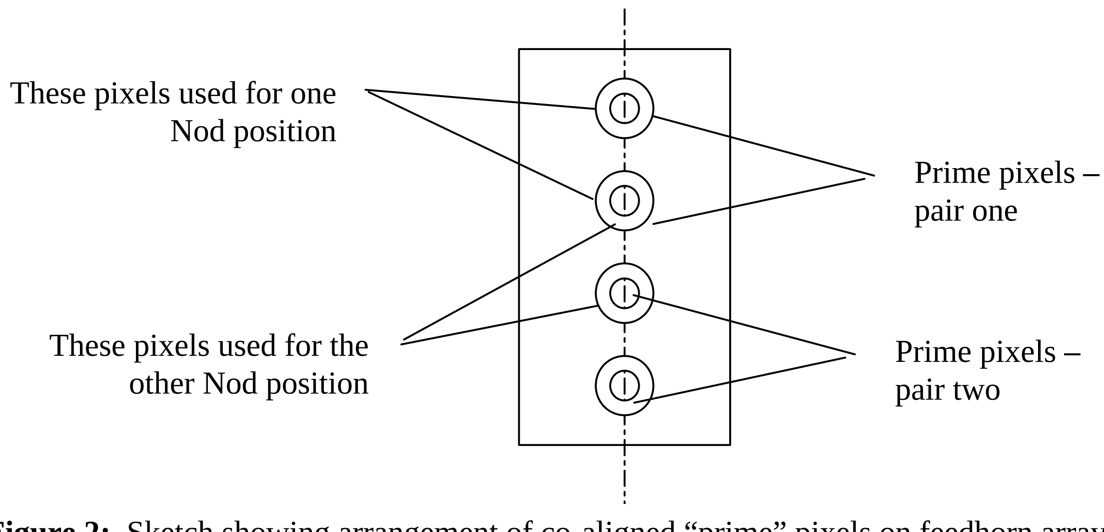

Figure 2: Sketch showing arrangement of co-aligned "prime" pixels on feedhorn arrays. The source is chopped from one of the pixels in a pair to the other. When the satellite is nodded one pixel of the other pair is used.

3. Redundancy in the 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 3. 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 diameter of the short wavelength feedhorns is reduced from the true 2Fλ size of 2.5 mm 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. The long wavelength array is rotated by 30^o w.r.t. to the short wavelength giving 13 overlapping pixels. This makes the spectrometer observations more efficient and removes the dependency on only the central pixel.

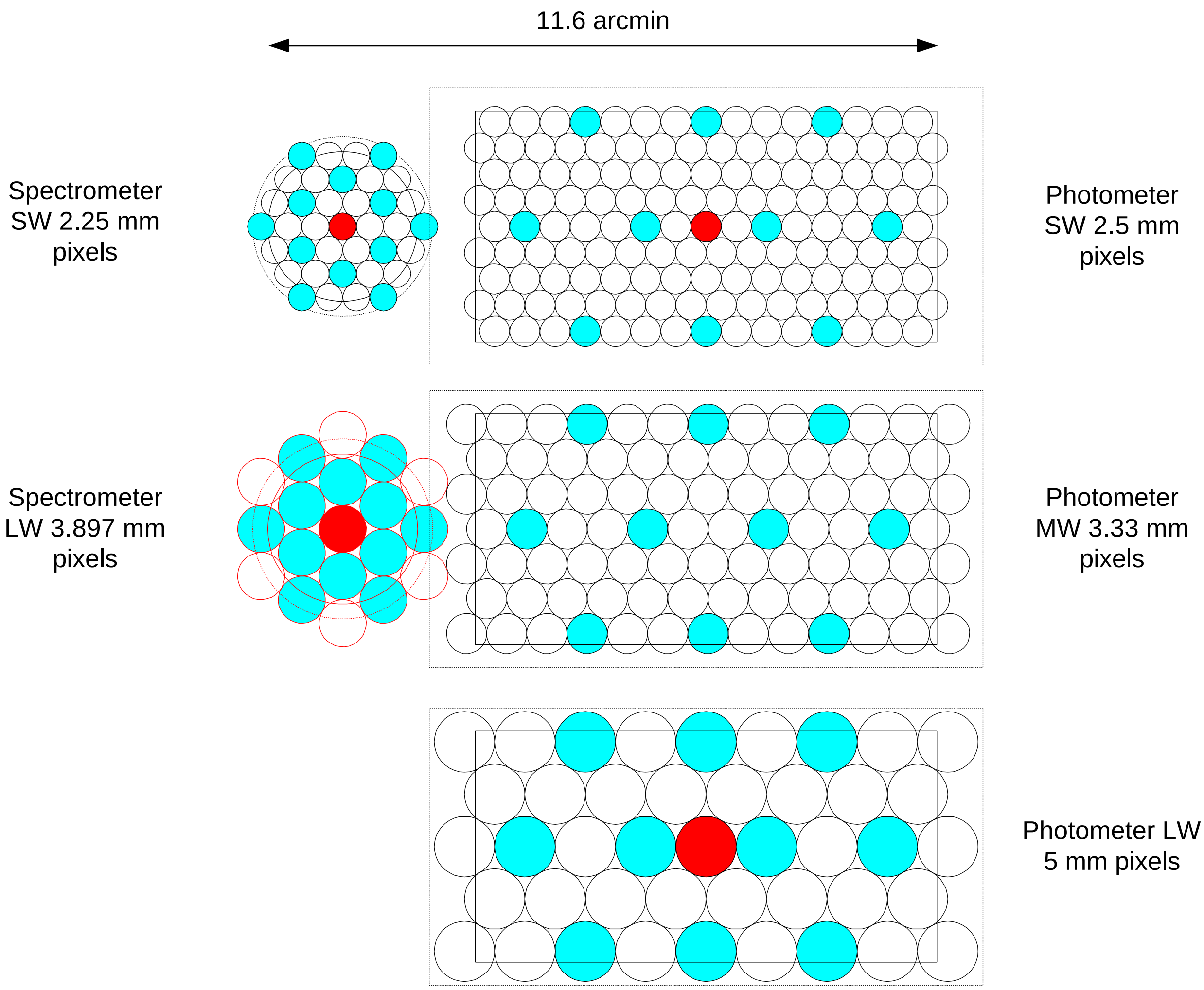

Figure 3: Proposed layout of the photometer and spectrometer focal planes. The geometric FOV in each case is shown as the solid black line – the dashed line is the conanical 20% overised FOV that will allow for any diffraction. The instrument optics will allow the over sized FOV onto the sky albeit with some vignetting at the edges. The red pixels are aligned with the instrument boresight for each channel and the blue pixels view the same point on the sky.

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
- Structural failure in the 300 mK system leading to thermal short
- 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 given here.

1. The photometer feedhorn arrays will be arranged as blocks; i.e. sharing of control lines; amplifiers; ADC's etc. The allocation of pixels into blocks may not be an entirely free choice, however, the prime pixels in each array should not share a single block if at all possible as the loss of any one of these across the three arrays would cause a loss in operational efficiency.

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

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 to enable V-I's on detectors under different loading 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