SPIRE

SUBJECT: **Operating Modes for the SPIRE Instrument**

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DOCUMENT No: **000320**

ISSUE: **Draft** **Date:** **12 November 1999**
1.0 **30 November 1999**

CHECKED BY: **…………………………………. Date: ………………………….**

APPROVED BY: **…………………………………. Date: ………………………….**

Distribution

Change Record

ISSUE	DATE	Comments
Draft	12/11/1999	First proper draft with all sections except 6 and 7
1.0	30/11/1999	Issued Prior to Warm Electronics Review

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Glossary

SPIRE	Spectral and Photometric Imaging REceiver

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1. INTRODUCTION

This document describes the expected operating modes for the SPIRE instrument on FIRST. It gives a detailed description of the operations required to implement each operating mode in order to place requirements on the components of the SPIRE instrument other than the cold FPU – i.e. the warm electronics; on-board software and ground segment. The underlying assumption in this document is that the configuration of the instrument cold FPU is as defined in AD2, the *SPIRE Instrument Requirements Document* (IRD). This document describes how the sub-systems defined in the IRD are to be operated; it is not intended to place further requirements on the cold FPU sub-systems.

Section 2 gives the assumptions underlying the description of the operating modes and the expected conditions for the satellite operations. Section 3 is a brief description of each of the operating modes and how the instrument is switched from one mode to another; section 4 goes into more detail. Section 5 describes the observatory functions that are required to implement the SPIRE observations. Section 6 deals with possible degraded instrument operation due to sub-system failure. Section 7 details the instrument functions and data configurations required to carry out all SPIRE operating modes.

The calculation of the data rate required for the SPIRE observing modes is given in appendix A. Examples of how typical observations might be constructed are given in appendix B.

In this first draft there is a concentration in this document on the observing mode of the instrument and the required functions of the instrument hardware; on-board data processing and the Satellite Functions required to carry out the SPIRE observations.

2. MISSION ASSUMPTIONS

2.1 FIRST and SPIRE

The Far Infrared and Submillimetre Telescope (FIRST) mission is dedicated to observing the cosmos at wavelengths from 85 to 700 µm. It consists of the 3.5 m telescope at a temperature of 80 K with a suite of focal plane instruments cooled to <11 K in liquid helium cryostat. A service module (SVM) is provided on the satellite for the instrument warm electronics units and the satellite control systems.

The SPIRE instrument is one of three focal plane instruments for FIRST. It will make observations in the 200 to 670 µm band using bolometer detectors. The focal plane unit of SPIRE is operated at cryogenic temperature (<11 K) and the detectors are operated at ~300 mK. This temperature is provided by a ^{3}He sorption cooler.

The instrument consists of two sub-instruments:

SPIRE-P:	A three band imaging photometer using three separate bolometer arrays with fixed optical band pass filters with resolution of about 3. This will simultaneously image a 4x8 arcmin (TBC) field of view onto three bands centred on 250, 350 and 500 µm (TBC). A beam steering mirror will be used to move the image of the sky over the arrays to chop the field view of the instrument onto the sky background close to the object of interest and to give complete spatial sampling of the field of view by stepping the image by fractions of the Airy pattern diameter.

SPIRE-S: An imaging Fourier Transform Spectrometer (FTS). This uses two bolometer arrays to give spectrally resolved images of a small (~2.6 arcmin (TBC)) area of sky. The two bolometer array have nominal optical bands of 200-300 and 300-400 μm, with a possible extension to 670 μm. The maximum resolution of the instrument will be about 0.04 cm^{-1}. The spectrometer shares the input optics to the instrument with the photometer. This includes the beam steering mirror which can be used to step the image across the arrays to give full spatial sampling of the field of view.

It is assumed that the photometer and spectrometer will be operated independently.

2.2 Other FIRST Instruments

There are two other instruments on FIRST:

HIFI (The Heterodyne Instrument for FIRST): A heterodyne spectrometer to give very high resolution spectroscopy over the 2700 to 480 GHz frequency band.

PACS (Photo-conductor Array Camera and Spectrometer): A broadband imaging photometer and medium resolution imaging spectrometer operating over the 85 – 200 μm waveband.

The HIFI cold FPU and local oscillators will be switched off during all SPIRE observations. It is possible that SPIRE will be used to take simultaneous images with the PACS instrument – this is called the PARTNER mode.

2.3 Operations Model

2.3.1 Mission Operations

The following assumptions are made about how FIRST/SPIRE will be operated:

- FIRST will carry out autonomous operations during 22 out of every 24 hours – during this time there will be no ground contact.
- During autonomous operations all instrument data will be passed into the satellite on board solid state recorders at an average rate of no more than 100 kbit/sec averaged over 24 hours (TBC).
- During autonomous operation the instrument will be responsible for its own health and safety monitoring and will be capable of switching to a defined safe mode in the event of a detected anomaly. The spacecraft will also monitor the instrument and will switch the instrument to a pre-defined mode in the event of a detected anomaly in the DPU operation.
- Nominal ground contact will be for 2 out of every 24 hours.
- During ground contact all data will be transferred from the satellite solid state recorders to the ground station and the commands for the next 22 hours of operations will be uplinked.
- Some instrument operations, such as COOLER RECYCLE (see below) will be carried out during ground contact period.
- When not being actively used SPIRE will be switched to a STANDBY mode.
- The default operating scenario is for SPIRE to be left on at all times to preserve the on-board software and configuration data in the instrument volatile memory.

2.3.2 Observe Mode Scenario

Figure 2-1 shows the assumed model for the definition of the SPIRE observations and the method by which the astronomer inputs his/her observing programme. The elements of the model are as follows:

- **AOT** (Astronomical Observation Templates): The observer is given a choice of observation types that can be carried out by the instrument and telescope. These will be limited to no more than ten (TBC). He/she is given a template to fill in with the details of the sources to be observed and the parameters for the particular observation. At this stage the parameters are in astronomical terms – source name; RA, DEC; signal-to-noise; area to mapped; spectral range and resolution etc.

- **Observation**: The First Science Centre (FSC) takes the inputs from the astronomer via the AOT and is responsible for their conversion into an OBSERVATORY FUNCTION with parameters for the SPACECRAFT FUNCTIONs; INSTRUMENT FUNCTIONs and INSTRUMENT DATA CONFIGURATIONs that make up the OBSERVATORY FUNCTION. The OBSERVATORY FUNCTION is a template which, when instantiated with the actual parameters for a given source and observation type, becomes an OBSERVATION of fixed time length which can be scheduled into an OBSERVING SEQUENCE.

- **Observing Sequence:** The OBSERVATIONS required for a particular programme are put together into an OBSERVING SEQUENCE to be implemented by the MOC. The scheduling of the OBSERVING SEQUENCE is defined by the FSC and implemented by the MOC.

- **Observatory Function:** A combination of SPACECRAFT and INSTRUMENT FUNCTIONS which, with the appropriate input parameters, allow any OBSERVATION to be carried out.

- **Satellite Functions:** These are the operations that can be carried by the satellite to point the telescope such as line scan; raster; staring etc They are fully described in AD1 (*FIRST Scientific Pointing Modes)* – for information they are summarised in section 2.4. Satellite functions also include operations by the spacecraft on-board data handling sub-system (DHSS) to switch power to the instrument; send commands; collect data etc.

- **Instrument Functions:** These are the operations to be carried out with the instrument such as PHOTOMETER CHOP; PHOTOMETER JIGGLE; SPECTROMETER SCAN etc. Combined with the SPACECRAFT FUNCTIONS they fully define how an observation is to be carried out.

- **Instrument Data Configuration:** In addition to specifying how the instrument is to be operated for a given operation, the on-board data processing needs to be specified along with the data to be sampled and the manner in which the detector data is sampled. This will be done be choosing from a number of DATA CONFIGURATIONS such as PHOTOMETER FULL FIELD CHOP; SPECTROMETER SINGLE PIXEL etc etc.

- **Instrument Command Sequences:** The instrument will be operated by building the high level instrument functions from a command language built up of INSTRUMENT COMMAND SEQUENCES. These are an intermediate set of logical instrument control functions such as MOVE BSM or READ PHOTOMETER FRAME that allow the instrument controllers to build any required INSTRUMENT FUNCTIONS without resort to the low level commands in the native on-board software language.

- **On-board Software Commands:** This is the low level command language used in the on-board software in the warm electronics (DPU or DRCU).

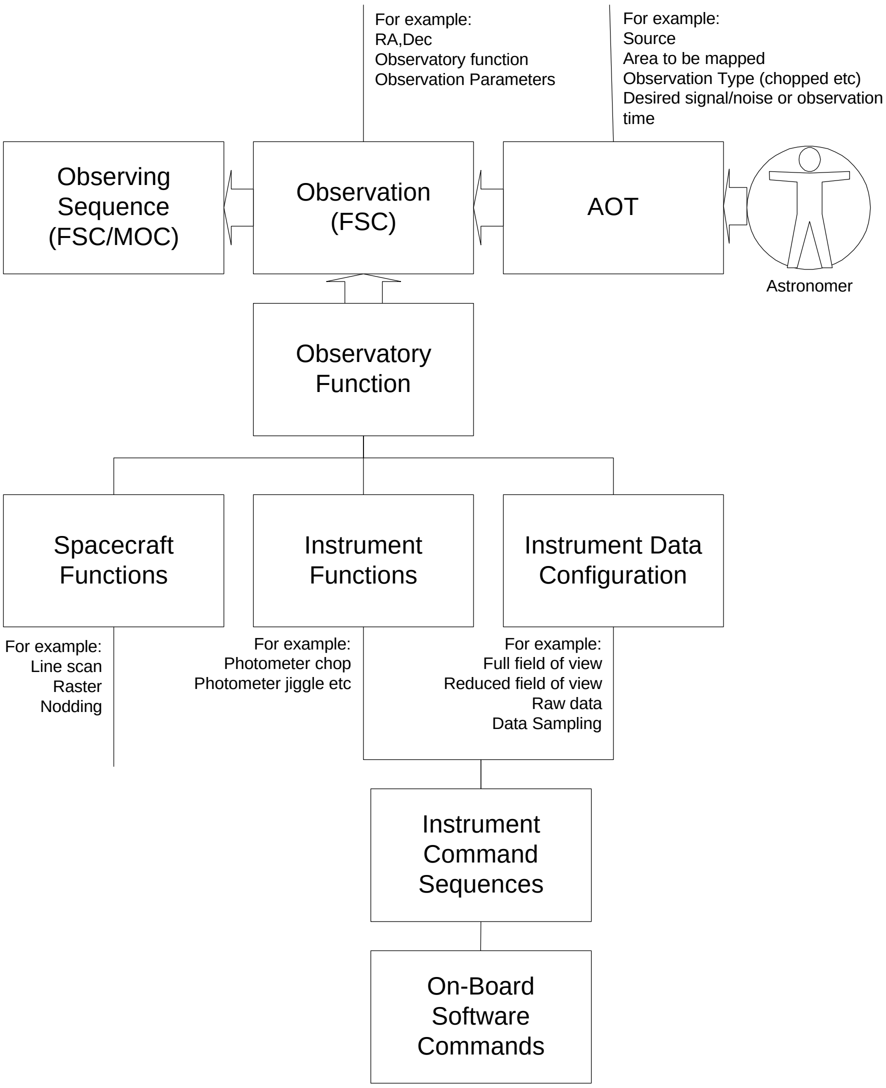


Figure 2-1: Diagrammatic representation of the connection between the various elements for the implementation of the SPIRE Observe Mode

2.4 Satellite Operations

This section describes the operations assumed to be available from the satellite and required by the SPIRE instrument for the pointing of the telescope. Full details of the spacecraft capabilities are given in AD1. See section 5 for more details on the implementation and the scientific merit of these operations.

2.4.1 Pointing

The satellite will be capable of pointing the telescope to within TBD arcsec absolute pointing in any direction on the sky. The pointing will be stable to within TBD arcsec 1-sigma 1-minute.

2.4.2 Nod

The NOD function of the telescope is an operation in which the target source is periodically moved from one instrument chop position to the other chop position by re-pointing the satellite. The pointing direction will change in the direction of the chopper throw – see figure 2-2.

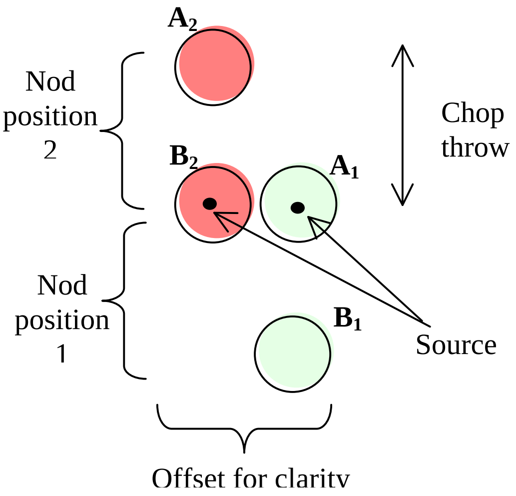


Figure 2-2: Pointing positions for a telescope NOD function. The circles represent the size of the telescope Airy pattern projected onto the sky. The two nod positions have been off set left and right for clarity. In reality A_1 and B_2 would be co-aligned

2.4.3 Raster

The RASTER Satellite Function is a series of fine pointing operations of separated by slews such that the pointing of the telescope axis moves in a raster pattern. Figure 2-3 shows how the raster pattern will be constructed.

2.4.4 Line Scan

In the LINE SCAN Satellite Function the satellite is slewed at a constant angular velocity along short parallel lines on the sky. Figure 2-4 shows how the operation is carried out.

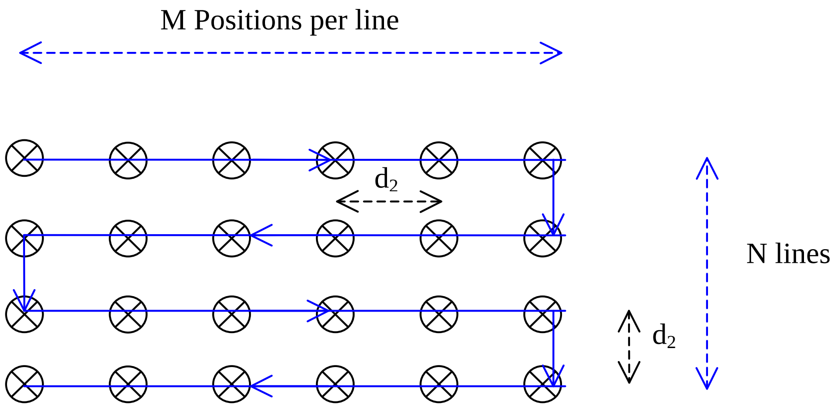


Figure 2-3: Pointing positions for a telescope RASTER function. The observation is specified in terms of M pointings per line separated by d_1 by N lines separated by d_2 arcsecs

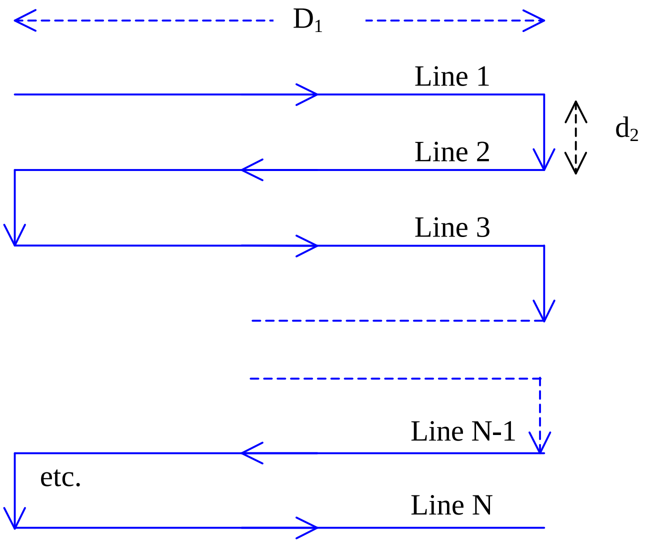


Figure 2-4: The LINE SCAN function of the telescope consists of a number of short slews of length D_1 separated by a distance d_2. The slews will be carried out in the order shown here

3. OVERVIEW OF OPERATING MODES

This section gives a brief description of the operating modes for the SPIRE instrument identified in the *Instrument Requirements Document* (AD2). Note that this list has been expanded to include the SAFE; INIT; TRNS; and TEST modes. An acronym of no more than four letters is given to each mode for identification purposes later in the document.

3.1 OFF Mode

All instrument sub-systems will be switched off - including the DPU and there will be no instrument telemetry.

3.2 ON Mode

The DPU will be switched on and can receive and interpret all instrument commands, but no other sub-systems will be switched on (including the DRCU). For engineering purposes it will be possible to command the instrument to switch on individual sub-systems from this mode. Full DPU housekeeping data will be telemetered.

3.3 Initialise (INIT) Mode

This is an intermediate mode between OFF and ON. This will be the mode the instrument enters after a power on or re-boot. In this mode only a limited sub-set of commands may be executed. This mode allows updates of DPU on-board software and/or tables to be carried out safely before they are used for instrument control.

3.4 Ready (REDY) Mode

The DPU and DRCU are powered on and the on-board software is ready to receive commands. No other sub-systems are switched on in this mode. DRCU housekeeping data will be telemetered.

3.5 Standby (STBY) Mode

The spacecraft may be pointed in an arbitrary direction (observing with another instrument for instance). The instrument will telemeter only housekeeping information, and perhaps some degraded science data - see below, at a rate very much lower than the full telemetry bandwidth. This is presently baselined to be the photometer detectors on and at 300 mK i.e. the cooler will have been recycled previous to entering STANDBY. All other sub-systems will be switched off.

3.6 Observe Mode (OBSV) Mode

There are two basic sub-modes for the observe mode Photometer and Spectrometer. The details of the OBSERVATIONS to be carried out in OBSERVE mode are given in section 5.

3.7 Cooler Recycle (COOL) Mode

The ^{3}He cooler requires recycling every 46 hours (TBC). During this time the instrument will be switched off except for vital housekeeping and cooler functions (TBC). The recycling takes 2 hours (TBC) to complete with another N hours (TBD) before instrument operations can recommence. During the 2 hours recycling the heat load on the helium bath is 50-100 mW (TBC).

3.8 SAFE Mode

The instrument will be switched to SAFE mode in the event of any anomalous situation occurring whilst in autonomous operation. This will be with the DPU on having been rebooted from a restricted set of software stored in ROM.

3.9 Mode Transition

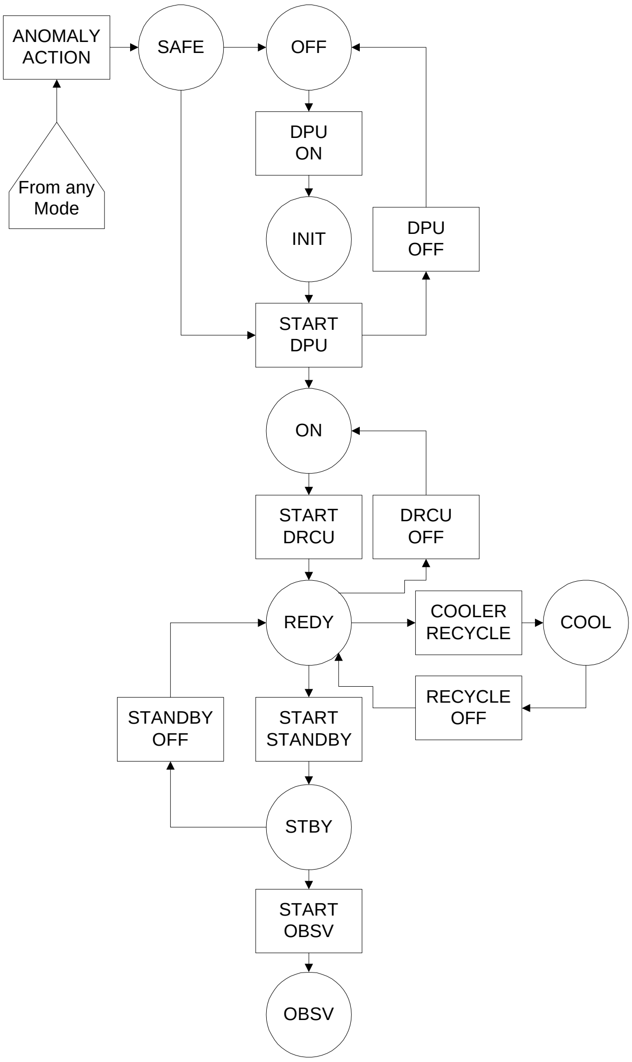


Figure 3-1: Logical transition flow between SPIRE operating modes. The boxes represent instrument command sequences to switch a mode on. The corresponding sequences to switch a mode off are not shown for clarity but should be assumed.

Figure 3-1 shows the logical transition from one operating mode to another.

3.10 Non-standard Data Configurations

In this section the data configurations that will be required for testing and commissioning the instrument both on the ground and in-flight are briefly described.

3.10.1 Commissioning and Calibration (COCA)

During the commissioning and performance verification phases of mission operations, many housekeeping and other health check parameters will be unknown; poorly defined or under investigation. This configuration allows the limits on selected health check parameters to be ignored by whatever real time monitoring systems are in place on the spacecraft or instrument.

3.10.2 Transparent (TRNS)

This can be used for any operating mode that utilises on-board processing or data compression. All on-board processing is switched off and the telemetry stream is filled with “raw” data from the detectors; mechanisms etc.

3.10.3 TEST

Here a fixed configuration of the instrument is used to generate a known set of data. It will be used during integration and verification for de-bugging the interface between the instrument and the spacecraft. It will also be useful in-flight for testing the system after switch on or after an anomaly.

4. DETAILED OPERATING MODES

Instrument configuration for each mode; Power dissipation for each mode; Commanding when in a mode; Telemetry contents and rate for each mode; S/C operations for each mode; Timeline and synchronisation for each mode

4.1 Instrument Configuration for Operating Modes

Table 4.1-1 shows a matrix between the defined operating modes and the actions to be carried out by the SPIRE instrument. The instrument actions are as defined below. This top-level matrix gives an indication of what actions are possible in a given operating mode and at the same time what sub-systems are to be operated. The OBSERVE MODE is not broken down into the separate INSTRUMENT FUNCTIONS – see section 5. This means that the table shows both spectrometer and photometer elements being used for all observations – this will not be the case as the two sub-instruments will not be used together.

	Operating Mode							
Instrument Action	OFF	INIT	ON	REDY	STBY	COOL	OBSV	SAFE
DPU Commanding	No	Yes	Yes	Yes	Yes	No	No	Yes
DRCU Commanding	No	No	Yes	Yes	Yes	No	No	No
Instrument Command Decoding and Execution	No	No	No	Yes	Yes	Yes	Yes	No
Housekeeping Acquisition	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Data Formatting	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Telemetry Sending	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fridge Recycle Control	No	No	No	No	No	Yes	No	No
Fridge Heater Control	No	No	No	No	No	No	Yes	No
FPU Temperature Regulation	No	No	No	No	Yes?	No	Yes	No
Photometer Detector Control	No	No	No	No	Yes?	No	Yes*	No
Spectrometer Detector Control	No	No	No	No	No	No	Yes*	No
Photometer Calibration Source Control	No	No	No	No	No	No	Yes*	No
Spectrometer Calibration Source Control	No	No	No	No	No	No	Yes*	No
FTS Mechanism Control	No	No	No	No	No	No	Yes*	No
Beam Steering Mirror Control	No	No	No	No	No	No	Yes*	No
Data Processing	No	No	No	No	Yes?	No	Yes*	No

Table 4.1-1: Instrument operations possible or required for each SPIRE operating mode.

*Which sub-system is used depends on the particular observation

Instrument Action Definitions

Commanding:

There will be three types of instrument action associated with telecommands:

DPU Commanding: Commands will be sent just to the DPU to do something to itself – RAM/ROM Dump; RAM patches etc

DRCU Commanding: Commands will be sent transparently through the DPU direct to the DRCU to make individual sub-systems do things; update FPGA tables; set latches to specific values etc.

Instrument Commanding: Higher level procedure commands sent to DPU – basically the INSTRUMENT FUNCTIONS – which it interprets into low level commands to the DCRU and passes on.

Housekeeping Acquisition:

Taking housekeeping parameters from the appropriate sub-systems and sticking into the appropriate HK packet – i.e. might be one for DPU and another for the DCRU etc.

Data Formatting:

Action of DPU in collating data from sub-systems and on board processing and sticking into appropriate packets with time stamping; headers etc.

Telemetry Sending:

Action of DPU in responding to the S/C DHSS request for data from SPIRE and sending it.

Fridge Recycle Control:

Operation of Warm Electronics to switch ^{3}He cooler heat switches and heaters on and off as appropriate to recycle the fridge

Fridge Heater Control:

Action of the Warm Electronics to operate the ^{3}He fridge by adjusting the current flowing through the pump heater to keep the cold tip temperature constant.

FPU Temperature Regulation:

Action of the Warm Electronics to maintain constant temperature of what ever bits of the cold FPU are temperature controlled by using PID type feedback between thermometers and heaters. May NOT be implemented.

Photometer Detector Control:

Action of the DCRU to readout the photometer arrays in synchronisation with other mechanisms or S/C operations as appropriate. DCRU action will include the reduction of the raw readout rate down to the rate required for input into the data processing system (either in DPU or DCRU) – i.e. de-modulation; co-addition; de-spiking etc.

Spectrometer Detector Control:

Action of the DCRU to readout the spectrometer arrays in synchronisation with other mechanisms or S/C operations as appropriate. DCRU action will include the reduction of the raw readout rate down to the rate required for input into the data processing system (either in DPU or DCRU) – i.e. de-modulation; co-addition; de-spiking etc.

Photometer Calibration Source Control:

Action of the DCRU to switch on and control the photometer calibration source. This will include modulating the current through the device at the appropriate rate – up to 5 Hz (TBC).

Spectrometer Calibration Source Control:
Action of the DCRU to switch on and control the spectrometer calibration source(s). It is expected that these will be operated as DC device with no short period modulation required.

FTS Mechanism Control:
Action of the DCRU to move the FTS mirrors by controlling the position with whatever feedback loop between the position sensor and the linear motor.

Beam Steering Mirror Control:
Action of the DCRU to move the BSM by controlling the position with whatever feedback loop between the position sensor and the linear motor.

Data Processing:
Action of the DCRU and/or DPU to process the output of the detectors in any mode to a data rate compatible with the average S/C telemetry capability. This will be like averaging; lossless compression etc.

4.2 Power Dissipation

In this section the global power dissipation figures for each mode for the warm electronics units and the various cryogenic stages are given. The situation for the OBSERVE mode is complicated as it will depend on the precise INSTRUMENT FUNCTION being used and which detector option is chosen. OBSERVE MODE is there fore treated separately in section 5.

	Operating Mode						
Dissipating Sub-System	OFF	INIT	ON	REDY	STBY	COOL	SAFE
DPU	0	15 W	15 W	15 W	15 W	15 W	15 W
DCRU	0	0	0	TBD	53/171/71 W*	TBD	0
BAU	0	0	0	0	3/0/1 W*	0	0
Detectors (15 K)	0	0	0	0	0/0/33 mW*	0	0
Detectors (4 K)	0	0	0	0	0	0	0
Detectors (2 K)	0	0	0	0	5/0.5/0 mW*	0	0
Parasitics (4-K)	4 mW	4 mW	4 mW	4 mW	4 mW	4 mW	4 mW
Parasitics (2 K)	2.5 mW	2.5 mW	2.5 mW	2.5 mW	2.5 mW	2.5 mW	2.5 mW
Cooler Heater	0	0	0	0	0	100 mW	0

Table 4.2-1: Estimated power dissipation for all operating modes except OBSV.

*These figures are for the different detector options CEA/GSFC/JPL.
All figures in this table are subject to revision.

4.3 Telemetry

In this section the expected telemetry contents and rate for each operating mode are discussed except for the OBSERVE mode – again this is complex and is dealt with in section 5. The contents of the TELEMETRY CONFIGURATIONS that will be used for the different operating modes are indicated in table 4-3.1. Detailed discussion of the packet construction and contents for these configurations is beyond the scope of the present document, except to note that the telemetry contents listed here do not necessarily have a one to one correspondence with the packet contents. Table 4-3.2 lists TELEMETRY CONFIGURATIONS that will be used for each of the operating modes. The entries in this table are the estimated telemetry rate for the mode in kbit/second.

Telemetry Configuration	**Telemetry Contents**
DPU Housekeeping	DPU Internal Supply Voltages DPU Internal Supply Currents DPU Temperatures Specific DPU OBS flags for example: Command received counter Command executed counter Current command buffer contents Memory status Commands sent counter etc, etc
DRCU Housekeeping	DRCU Internal Supply Voltages DRCU Internal Supply Currents DRCU Internal Temperatures BAU Internal Temperatures Specific DRCU OBS Flags – similar to DPU Cold FPU temperatures
Instrument Housekeeping	Instrument status flags – e.g. sub-system X redundant coil Y is ON etc etc…. Sub-system voltages; currents; counters etc.
SPIRE Temperatures	S/C monitored SPIRE temperature channels
Serendipity	Low rate, highly compressed detector data For example we could

Table 4-2.1: Brief description of TELEMETRY CONFIGURATION contents.

	Operating Mode						
Telemetry Configurations	OFF	INIT	ON	REDY	STBY	COOL	SAFE
DPU Housekeeping	No	~0.5 kbps	~0.5 kbps	~0.5 kbps	~0.5 kbps	~0.5 kbps	~0.5 kbps
DCRU Housekeeping	No	No	No	~0.5 kbps	~0.5 kbps	~0.5 kbps	No
Instrument Houskeeping	No	No	No	No	~2 kbps	~2 kbps	No
SPIRE Temperatures	<0.1 kbps	<0.1 kbps	<0.1 kbps	<0.1 kbps	<0.1 kbps	<0.1 kbps	<0.1 kbps
Serendipity	No	No	No	No	~1 kbps	No	No

Table 4.3-2: Expected data configurations and telemetry rates for all operating modes except OBSV. All figures are TBC.

4.4 Satellite Functions

This section describes gives the expected spacecraft operations that are or may be required to be enacted for each operating mode – again the OBSERVE MODE is complex and is dealt with in section 5. For most of the modes listed here the satellite functions routinely required are likely to be minimal. The ability of the s/c to switch SPIRE to SAFE is needed for all modes except INIT and OFF. The titles of the procedures which call these satellite functions are given in square brackets and correlate to figure 3-1.

Switch SPIRE from OFF to INIT [DPU ON]
The spacecraft switches the 28 V line to the DPU on. This can only be enacted by a direct command to the spacecraft – by definition the SPIRE instrument cannot request itself to be switched on!

Switch SPIRE from ON to REDY [START DRCU]
The spacecraft switches the 28 V line to the DCRU on. This will be a direct command to the spacecraft either from the ground or as part of an automated switch on sequence. It is expected that any automated switch on sequence would involve a confirmation of instrument status from the DPU to the DHSS before the 28V to the DRCU was switched on.

Switch SPIRE from REDY to ON [DRCU OFF]
The spacecraft switches the 28 V line to the DCRU off. This could be requested either by the DPU or by direct command to the spacecraft.

Switch SPIRE from ON to OFF [DPU OFF]
The spacecraft switches the 28 V line to the DPU off. This could be requested either by the DPU or by direct command to the spacecraft.

Switch SPIRE to SAFE [ANOMALY ACTION]
The spacecraft switches the 28 V line to the DRCU off . This may be requested by the DPU or in response to an anomaly detected by the spacecraft DHSS.

Hardware Reset of the DPU [?]
The spacecraft will have the ability to enact a hardware reset of the DPU that will, effectively, switch the DPU to SAFE mode whereby it is operating using a restricted set of software located in ROM. This mode is required in case of DPU latch up or other failure and, unlike simply switching off the DPU 28V, allows the contents of the RAM and mass memory to be retained for diagnostic purposes. *Is this actually required?*

Monitor SPIRE Temperature
A number of the temperature sensors on both the SPIRE cold FPU and the SPIRE warm electronics units are monitored directly by the spacecraft DHSS. The spacecraft is required to take certain actions (e.g Switch SPIRE to SAFE) if these temperatures go outside pre-defined limits. *(Not sure we actually want this but leave it in anyway!)*

Receive SPIRE Data
In all modes except OFF the SPURE DPU will be making telemetry packets available for on-board storage in the spacecraft Solid State Recorders (SSRs) prior to telemetry to the ground. It is expected that the spacecraft will be collecting these regularly from the SPIRE instrument to prevent overload of

the instrument on-board storage capabilities. The regularity with which the data must be collected will depend on the operating mode.

Send SPIRE Commands
In all modes except OFF the SPIRE DPU will be capable of receiving and interpreting commands from the spacecraft DHSS. The spacecraft will pass these to the instrument in a predefined sequence at predefined times, or in response to an instrument status confirmation from the DPU, to ensure the correct operation of the instrument operating mode. The SPIRE instrument will execute the commands in the order they are received and at the time they are received.

Instrument Parameter Monitoring
The spacecraft will monitor the voltage and current of the power supply to the DPU and DCRU. It will also be given knowledge of the instrument configuration by the DPU providing instrument “context” information in the SPIRE housekeeping. The spacecraft will take specific action (e.g. Switch SPIRE to SAFE) if an out of limits anomaly is detected for the DPU or DCRU power supply.

Instrument Event Monitoring
Events detected by the DRCU or DPU during autonomous operation and which require action by the s/c will be notified to the DHSS via a dedicated “Event Packet”. The DHSS is expected to monitor these and take a pre-set action when a particular event is detected – notably a “Go to SAFE” flag in an event packet.

4.5 Operations Timelines

There are requirements on the timing and status verification of certain instrument or spacecraft actions when going from one operating mode to another. There are also requirements on the timing and status verification of instrument and spacecraft actions within the execution of a given operating mode – most notably the OBSERVE MODE, but also the cooler recycling operation.

In this section the transitions from one mode to another up to STANDBY mode are described as well as the operation of the cooler recycling. The transition from STANDBY to OBSERVE and the OBSERVE mode operations are described in section 5.

4.5.1 OFF to STANDBY

In this section the logical sequence and status confirmation requirements for switching the instrument from OFF to STANDBY MODE are described. In doing so all the “forward” transitions between all modes is described except for between STANDBY/OBSERVE; READY/COOLER RECYCLE and from any mode to SAFE. The transition from OFF to STANDBY may be carried out by the execution of a sequence of **On-Board Command Procedures (OBCP)** and the appropriate, automatic, verification and status confirmations or by direct commands from the ground during ground contact with confirmations in real time by the spacecraft operators.

Initial Instrument State	Procedures	Events/verification	Final Instrument State
OFF	**DPU ON**	1. Current to instrument stable at TBD A – verified by S/C 2. DPU boots from ROM 3. INIT mode data configuration starts – housekeeping packets	INIT

Initial Instrument State	Procedures	Events/verification	Final Instrument State
		generated 4. Confirmation of DPU status from DPU housekeeping	
INIT	**START DPU**	1. DPU RAM load 2. ON mode data configuration starts 3. RAM dump content verification 4. Confirmation of DPU status from DPU housekeeping	ON
ON	**DRCU ON**	1. Current to DCRU stabilises at TBD A – verified by S/C 2. DRCU boots from ROM 3. REDY mode data configuration starts 4. Confirmation of DCRU status from DRCU housekeeping	REDY
REDY	**DRCU START**	1. DRCU RAM load 2. DRCU RAM dump content verification 3. Confirmation of DRCU status from DRCU housekeeping	REDY
REDY	**START STANDBY**	1. STANDBY mode data configuration started i.e. Science data transfer from DCRU to DPU; STANDBY mode science data formatting started etc 2. Photometer detectors switch on 3. Confirmation of instrument status from DPU; DRCU and instrument housekeeping	STBY

Table 4.5-1: SPIRE switch on sequence from OFF to STBY.

4.5.2 STANDBY to OFF

Table 4.5-2 describes the sequence of command procedures and events for switching the SPIRE instrument from STANDBY to OFF. Again this sequence could be generated by a single command to the spacecraft to switch the instrument off – e.g. at the end of an observing period – in which case the sequence could follow automatically with the appropriate status confirmations. Alternatively each step could be initiated by a direct command during ground contact.

Initial Instrument State	Command Procedures	Events/verification	Final Instrument State
STBY	**STANDBY OFF**	1. DCRU switches off all sub-systems 2. READY mode data configuration starts 3. Verification that all sub-systems	REDY

Initial Instrument State	Command Procedures	Events/verification	Final Instrument State
		are switched off from DRCU housekeeping	
REDY	**DRCU OFF**	1. Current to DCRU falls to below TBD Amps 2. ON mode data configuration starts 3. Confirmation of DRCU status from DPU and s/c housekeeping	ON
ON	**DPU OFF**	1. Current to DPU falls to below TBD Amps 2. Confirmation of DPU from s/c housekeeping	OFF

Table 4.5-2: SPIRE procedures for switch off sequence

4.5.3 Switching to SAFE

In this section the actions taken following an instrument anomaly whilst in autonomous operation are outlined. It is assumed that switching from any mode to SAFE is always going to be initiated by the DPU.

Initial Instrument State	Command Procedure	Events/verification	Final Instrument State
OBSV STBY REDY COOL	N/A	1. Hard out of limits or other anomaly (DRCU watchdog etc) detected by on-board software	N/A
OBSV STBY REDY COOL	**ANOMALY ACTION**	1. DPU sends commands to DRCU to attempt to switch all sub-systems to off as gracefully as possible 2. DPU sets “Go to SAFE mode” flag in telemetry	Not Determined
Not Determined	**START SAFE**	1. DRCU current falls below TBD Amps 2. Confirmation that DRCU is off from s/c housekeeping 3. DPU resets using restricted (ROM) software 4. SAFE mode data configuration starts	SAFE

Table 4.5-3: Switching to SAFE mode

4.5.4 Cooler Recycling

The cooler is recycled by the following actions:

1. Switch on the cooler evaporator heat switch by applying current to the heat switch sorption pump heater pushing the gas from the pump into the body of the switch
2. Switch on the cooler pump heater
3. Wait for the gas to desorb and condense into the evaporator (N hours)
   How do we know when this has happened – does the heater current change – is it just elapsed time?
4. Switch off the pump heater current.
5. Switch off the evaporator heat switch by switching off the current to the heat switch sorption pump heater. As the pump cools the gas in the body of the switch will be re-adsorbed into the pump.
6. Switch on the pump heater heat switch
7. Wait for the pump to cool and the temperature on the evaporator cold tip to fall to the operating temperature.
8. When the operating temperature has been reached the cooler recycle is completed and the instrument can be switched to STANDBY

Table 4.5-4 describes the actions and events required for the cooler recycle mode.

Initial Instrument State	**Procedure**	**Events/verification**	**Final Instrument State**
REDY	**COOLER RECYCLE**	1. Set COOLER RECYCLE data configuration 2. Pump recycle is carried out (see above) 3. DPU confirms instrument status from DRCU housekeeping	COOL
COOL	**RECYCLE OFF**	1. Set REDY mode data configuration	REDY

Table 4.5-4: Recycling the cooler

5. OBSERVATORY FUNCTIONS

In this section the OBSERVATORY and INSTRUMENT FUNCTIONS outlined in section 2 are discussed in more detail, including the scientific reasoning behind the choice of a particular OBSERVATORY FUNCTION. Also given in this section are details of the required INSTRUMENT DATA CONFUGURATIONS and the INSTRUMENT COMMAND SEQUENCES required to build the nominal set of instrument functions.

Brief 'scientific' description of each observation
Observatory function description
Instrument Functions required
Instrument Data Configurations
Satellite Functions required
Typical timeline
Parameters

5.1 Observatory Functions for the Photometer (Feedhorn Option)

A suggested set of Observatory Functions for the photometer (feedhorn option) is listed below

FH_POF1 : Chop Without Jiggling
FH_POF2 : Seven-Point Jiggle Map
FH_POF3 : Sn-Point Jiggle Map
FH_POF4 : Raster Map
FH_POF5 : Scan Map Without Chopping
FH_POF6 : Scan Map With Chopping
FH_POF7 : Photometer Peak-Up
FH_POF8 : Operate photometer internal calibrator
FH_POF9 etc. : Special engineering/commissioning modes TBD ??

5.1.1 FH_POF1: Chop Without Jiggling

Purpose:
This Observatory Function is similar to what is often done on ground-based submillimetre telescopes. It is designed to make observations of a point or compact source of accurately known position, using a single pixel system or one pixel of a feedhorn array.

Description:

1. This Observatory Function is composed of the following instrument and Satellite Functions:

Instrument Function:	Photometer Chop
Satellite Function:	Nod

2. The telescope is pointed at a known position. The position on the sky is aligned with the prime detector which is, it is assumed, accurately co-aligned on each of the three detector arrays – see figure 5.1-2.

3. The beam steering mirror implements chopping at frequency f_{chop}.

4. If required, the telescope can also nod at frequency f_{nod}, where $f_{chop} >> f_{nod}$. There is no requirement that f_{nod} be a precise multiple of f_{chop}.

5. The source signal is computed as the difference between the signals recorded at the two nod positions, as shown in Fig. TBD. The purpose of nodding is to remove signal offsets due to asymmetrical background power in the two beams and to cancel the effects of any telescope temperature drifts. The nodding capabilities of the FIRST spacecraft are summarised in the *FIRST Scientific Pointing Modes Document*, p.10 (see Annex A).

Let S = Source signal
O_A = Offset signal for beam A
O_B = Offset signal for beam B

Then Signal $= (A_1 - B_1) - (A_2 - B_2)$
$= [(S + O_A) - O_B] - [O_A - (S + O_B)]$
$= 2S$

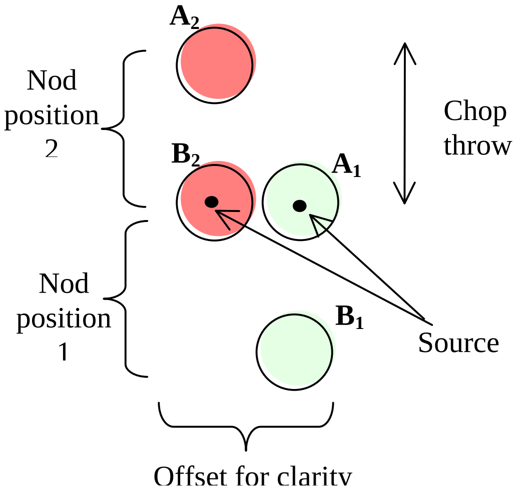


Figure 5.1-1: Telescope nodding to cancel out differences in the background power on the detector in the two chop positions.

6. Chopping between pairs of pixels gives maximum sensitivity because in that case the source is being observed all the time. For the feedhorn option, there is simultaneous overlap at all three wavelengths for 14 sets of detectors, as shown in Fig. TBD below (based on the JPL presentation

at the July PDR), if the wavelengths are in the ratio 1:0.75:0.5. The source is chopped between positions A_1 and B_1 when in nod position 1 and between A_2 and B_2 when in nod position 2. Signals can be determined from pairs (A_1, B_1) and (A_2 , B_2).

7. Chop distance on the array: $d_{chop} =$ 4Fλ at 500 μm = (4)(5)(0.5) = 10 mm at the array focal plane.

   Chop angle on the sky: $\theta_{chop} =$ (10 mm)(12.6 "/mm) = 126 arcsec. (2.1 arcmin.)

   Smaller or larger chop amplitudes can be used, but then it will not be possible to have exact overlap between detectors.

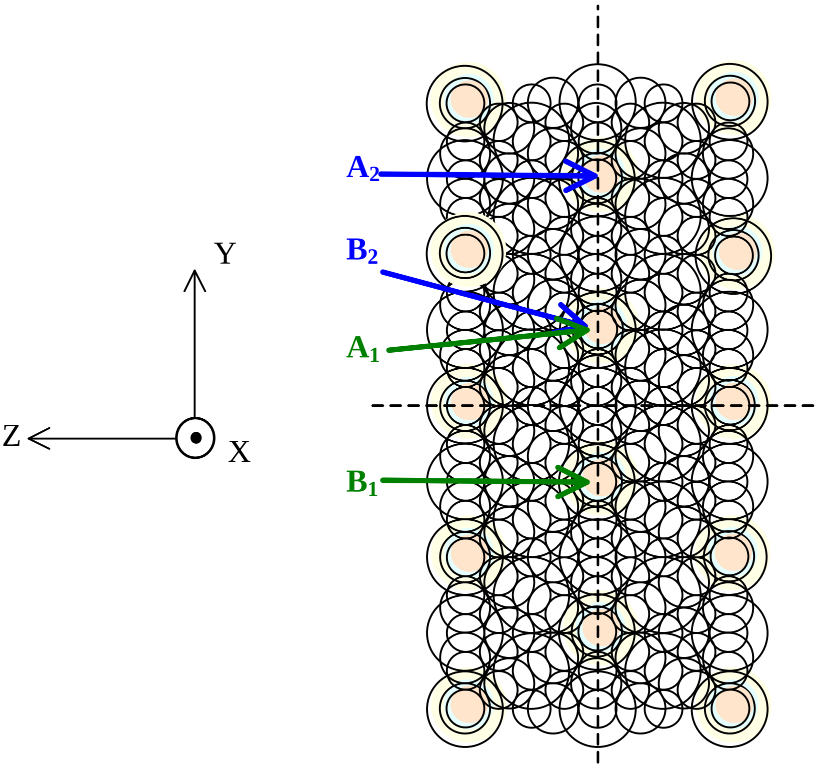


Figure 5.1-2: Sets of detectors (shaded) for which there is simultaneous overlap in all three bands for the feedhorn array option. For chopped observations, one of the sets nearest the centre of the array is used as to define the prime pointing

8. This mode requires pointing accuracy sufficiently good that the loss of 250-μm signal due to the pointing error is acceptable. The signal loss for an 18” Gaussian beam is tabulated below.

Offset (“)	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Loss (%)											
250 mm	0	0.2	0.9	1.9	3.4	5.2	7.4	10.0	12.8	15.9	19.3
350 mm	0	0.1	0.4	1.0	1.8	2.7	3.9	5.3	6.9	8.6	10.5
500 mm	0	0.1	0.2	0.5	0.9	1.3	1.9	2.6	3.4	4.2	5.2

The FIRST Absolute Pointing Error (APE) as given in the TBD is

Required: APE = 3.7” (TBD σ) ≡ 11%, 6%, 3% signal loss at 250, 350, 500 μm respectively
Goal: APE = 1.5” (TBD σ) ≡ 2 %, 1%, 0.5% signal loss at 250 350, 500 μm respectively
For most observations, 11% is not acceptable, but 2% is.

Therefore, for the feedhorn option, the required APE is not good enough to allow accurate photometry at 250 μm without peaking up, but the goal is sufficient to allow this. In the event that the pointing accuracy is not good enough to allow blind pointing then either

(i) this Observatory Function will not be used, or
(ii) it will be used but only when preceded by a peaking-up routine (see FH_POF6).

Chopping frequency:
The chopping frequency should be adjustable between frequencies of 0.3 (TBC) and 5 Hz. To simplify the data-processing, a standard set of 6-8 TBD values covering the allowed range could be could be adopted as the nominally available chopping frequencies.

Detector sampling:
The demodulated detector signals are to be sampled at 40 Hz with 16-bit resolution. The sampling parameters and the allowed chopping frequencies are summarised in Table TBD below.

Detector frame sampling rate for the demodulated detector signals	40 Hz (Δt = 0.025 sec) (TBC)
Number of bits per sample	16
Minimum number of samples per chop half-cycle	4
Minimum chopping period	$T_{min} = 8\Delta t = 0.2$ sec
Maximum chopping frequency	$1/T_{min} = 5$ Hz
Minimum chopping frequency	0.313 Hz (TBC)
Nominal chopping frequency	1.25 Hz (TBC)

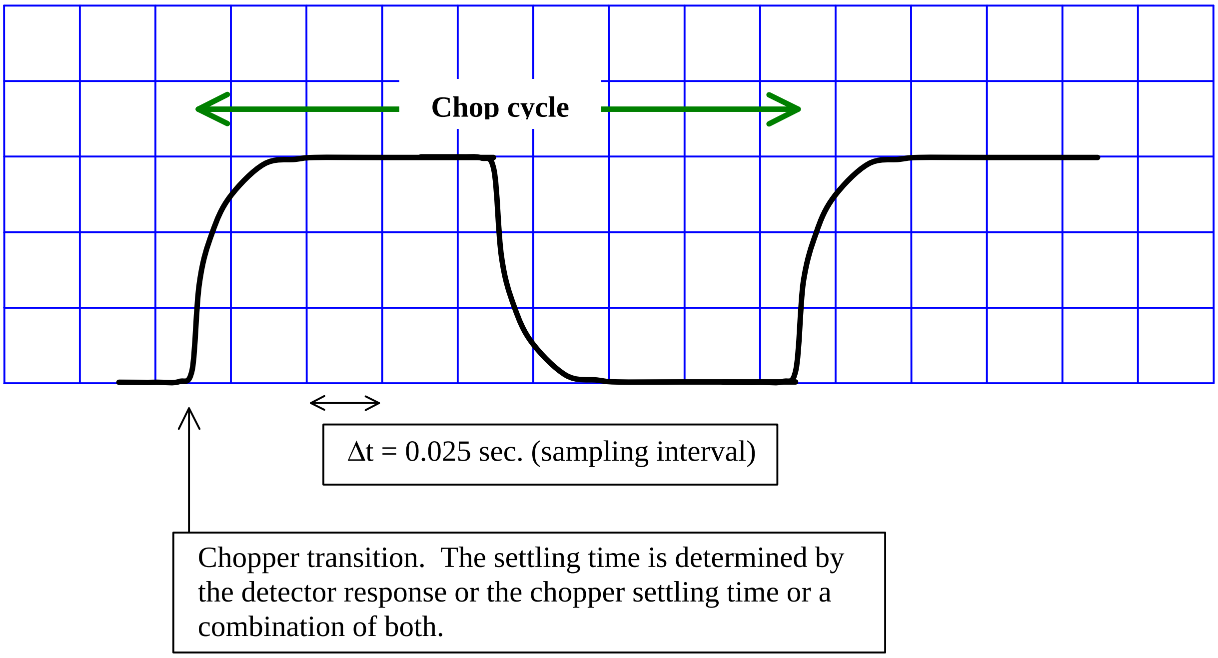
Table TBD: Details of detector sampling and chopping frequency

Figure 5.1-3 shows schematically the detector waveform and how it is to be sampled (for the case of a 5-Hz chop).

Synchronisation of the chopper and detector readout:
What is proposed here is for illustrative purposes only – I (BMS) think it’s a bit simplistic and will this requires much more thought – I’m not sure this even belongs in here rather than a document detailing the WE systems operations For instance the question of how we sample for slower chop frequencies; what happens if the frame read has variable length or the clocks drift apart during the observation etc etc….are not addressed here.

The chopper movement and the sampling must be synchronised so that the data are not sampled while the chopper is in motion between the two positions. It is proposed that this be ensured by the use of a flag generated from the BSM position servo: sampling of each half cycle begins at a specified time T after the BSM position reached flag has been produced.

Another method would be to heavily oversample the detectors, say at 100 Hz frame rate, and average or select only the relevant samples for inclusion in the telemetry stream. This has the advantage of not



Δt = 0.025 sec. (sampling interval)

Chopper transition. The settling time is determined by the detector response or the chopper settling time or a combination of both.

Figure 5.1-3: Schematic of the detector waveform and how it is to be sampled for the case of a 5-Hz chop.

requiring any synchronisation signals between the BSM and the detector control electronics at the expense of more complication in the on-board software.

Sampling of all 280 detectors will not be simultaneous. Question: How should the samples be interleaved?

Chopping and data sampling are carried out continuously, even while the telescope is moving from one nod position to another, and do not need to be synchronised with the telescope motions. Identification of the data corresponding to the transitions will be done on the ground using the telescope pointing history.

On-board processing and data rate (see Annex B, *SPIRE Detector Sampling Scheme and Data Rate* for details)

The DRCU does no on-board processing *(only for the scenario presented here – there may be some selection and/or averaging of the data to be done if the frame read rate is very much larger than the chop frequency)* . All the 16-bit samples taken at 40 Hz, are transmitted to the OBDH as part of the SPIRE science data stream for telemetry to the ground. The instantaneous data rate is (40 Hz) x (280 detectors) x (16 bits) = 179 kbs. Over a 24-hour period, the average data rate is: (179)*(0.9 observing efficiency)*(22/24 daily efficiency) = 148 kbs. Some lossless data compression would therefore be required to fit into 100 kbs. This might be fairly easy as the consecutive numbers within a chop half-cycle will be very similar. Should it prove unfeasible to transmit all of the samples to the ground unprocessed, the DRCU can halve the data rate by averaging pairs of samples within each chop half-cycle *(Harvey reckons this to be a bad idea – I think I agree as doing this takes us below the Nyquist sampling for the chop frequency)*. The average data rate over 24 hours is thus 148/2 = 74 kbs.

Instrument and Satellite Functions used and their parameters:

Table TBD: Photometer Observatory Function FH_POF1: Chop Without Jiggling

Instrument Function: Photometer Chop

No.	Parameter	Range of values	Nominal value	Comments
1	Prime detector	One of the two triple-overlap positions in the centre of the arrays	TBD	This position on the array is aligned on-source for nod position 1
2	Chop frequency	0.3 (TBC) - 5 Hz	TBD	
3	Chop direction	Any direction in the Y-Z plane	Parallel to the Y-axis	
4	Chop throw	Any value within the BSM range (±2 arcmin. in Y; ±0.25 arcmin in z)	126" on the sky parallel to Y-axis	
5	Total integration time	Min = 10 chop cycles Max = TBD	None	Only required for nodding OFF
Satellite Function: Nod				
1	Nodding	ON or OFF	ON	Nodding is optional
2	Nod period	Any value within allowed range	3 minutes	The SPMD does not give complete information on the ranges of chop amplitude and frequencies that are possible. A nominal figure of 3 minutes for the total nod cycle time is appropriate for SPIRE.
3	Nod direction	Same as the chop direction	Parallel to the Y-axis	
4	Nod throw	Same as the chop throw	126"	
5	Total number of nod cycles	Min = 2 Max = TBD	None	Specifies total integration time if nodding is ON

5.1.2 FH_POF2: Seven-Point Jiggle Map

Purpose:
This Observatory Function is designed for observation of an isolated compact source where uncertainties in the telescope pointing and/or the source coordinates mean that the accuracy of blind pointing cannot be relied upon. A small map must be made around the nominal pointing position to make sure that the source signal can be correctly estimated. It is effectively a combination of seven separate measurements using FH_POF1.

Description:

1. FH_POF2 is composed of the following instrument and Satellite Functions:

Instrument Function:	Photometer Chop Photometer 7-Point Jiggle
Satellite Functions:	Nod

2. The BSM is used to do to do small map 7-point hexagonal jiggle map with spacing θ arcsec., as shown in Fig. TBD below. A suitable value for θ is ~ 6”: this spacing is 1/3 of the beam at 250 µm (so consistent with full sampling), and is almost twice the APE.

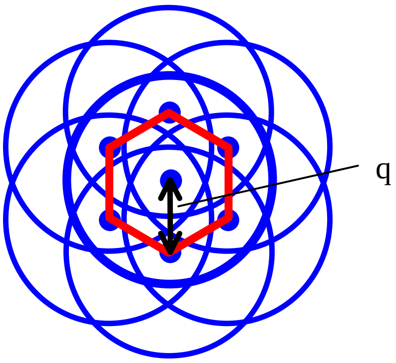


Fig. TBD: Seven-point hexagonal jiggle pattern. The order in which the seven points are visited is TBD

3. From such a 7-point map, the total flux of the source can be computed (see Griffin, Bock and Gear, *Comparison of sensitivities of 0.5F l, 1.0F l and 2.0F l arrays for the BOL*, 15 Dec. 1997.)
4. The central position is made to coincide with one of sets of three overlapping detectors to allow simultaneous optimised observations in the three bands.
5. The chop throw can be set at any desired value within the available range. A value of 126” improves the overall efficiency by allowing the source to be observed all the time in all bands.
6. Nodding is optional.
7. If nodding is ON, then the jiggle and nodding cycles must be coordinated (see below).

Jiggling frequency:
At least 5 chop cycles are required at each jiggle position. The minimum dwell time is therefore in the range 1 - 15 seconds for f_{chop} = 0.3 - 5 Hz.

A value of > 1 minute and < 3 min per nod cycle is appropriate, otherwise the telescope settling time overhead (10-18 seconds) will become prohibitive or the nod time will become excessive.

As a nominal case, we shall adopt f_{chop} = 2 Hz. We then have 10 seconds per jiggle position and about 70 seconds per jiggle cycle.

Coordination of jiggle and nod cycles:

The optimum operational sequence will be:

- N jiggle cycles (7 positions each)
- Nod and wait to settle
- Next set of N jiggle cycles

It is not likely that SPIRE will be allowed to control the timing of the telescope nodding motions - these will be pre-programmed in the daily up-link of 22-hour observing sequences. The nod period should therefore be predetermined to provide an integer number of complete jiggle cycles at each nod position. The jiggle cycle can commence on receipt of the on-target flag from the AOCS (can it?).

On-board processing and data rate (see Annex B, *SPIRE Detector Sampling Scheme and Data Rate* for details)
As for FH_POF1.

Instrument and Satellite Functions used and their parameters:

Table TBD: Photometer Observatory Function FH_POF2: Seven-Point Jiggle Map

Instrument Function: Photometer Chop

No.	Parameter	Range of values	Nominal value	Comments
1	Prime detector	One of the two triple-overlap positions in the centre of the arrays	TBD	This position on the array is aligned on-source for nod position 1. Common with FH_POF1.
2	Chop frequency	0.3 (TBC) - 5 Hz	2 (TBC)	Common with FH_POF1.
3	Chop direction	Any direction in the Y-Z plane	Parallel to the Y-axis	Common with FH_POF1.
4	Chop throw	Any value within the BSM range (±2 arcmin. in Y; ±0.25 arcmin in z)	126" on the sky parallel to Y-axis	Common with FH_POF1.
Instrument Function: Photometer Jiggle				
1	Jiggle pattern	7-point (central + hexagon) with separation θ	$\theta = 6$ arcsec.	
2	Number of chop cycles/jiggle position	Min = 5 Max = TBD	Such as to give roughly 1 minute per jiggle cycle	
3	Number of jiggle cycles/nod position	N = 1 - TBD	1	
4	Total integration time	Min = 2 jiggle cycles Max = TBD	None	Only required for nodding OFF
Satellite Function: Nod				
1	Nodding	ON or OFF	ON	Nodding is optional
2	Telescope nod period	Determined by the time taken for N jiggle cycles	Set to allow one jiggle cycle per nod position	
3	Nod direction	Same as the chop direction	Parallel to the Y-axis	
4	Nod throw	Same as the chop throw	126"	
5	Total number of nod cycles	Min = 2 Max = TBD	TBD	Specifies total integration time if nodding is ON

5.1.3 FH_POF3: n-Point Jiggle Map

Purpose:
This mode is for mapping objects or regions which are extended with respect to the SPIRE beam but smaller than a few arcminutes in size. Its implementation is very similar to FH_POF2.

Description:

1. FH_POF3 is composed of the following instrument and Satellite Functions:

    Instrument Function: Photometer Chop
    Photometer n-Point Jiggle

    Satellite Functions: Nod

2. The BSM is used to make an n-point jiggle map while chopping with a throw greater than the size of the object to be mapped (up to 4 arcmin.).

3. For full sampling at all wavelengths, n = 64. Considering the simplified case of square-packed horns, the step size must be $0.5\lambda/D$ = 9” at 250 μm and the number of steps must accommodate the need to cover the distance between two beams at 500 μm: $2\lambda/D$ = 72”. Eight steps in each orthogonal direction are thus required. The geometry of the juggle pattern is hexagonal for the hexagonally packed feedhorns, but the number of steps required is still 64.

4. To allow flexibility in the use of this mode, permitted values of n shall be 16, 32 and 64.

5. The sequence in which the jiggle positions are visited is TBD.

6. The chop throw is chosen to be greater than the size of the source to be mapped.

7. Nodding is optional.

8. If nodding is ON, then the jiggle and nodding cycles must be coordinated.

Jiggle frequency:

We assume for now that:

(i) a complete nod cycle must be executed at least every three minutes (TBC);
(ii) the dead time due to the nodding motions is 36 seconds (as indicated in the *SPMD*, p. TBD);
(iii) we will want to execute a complete jiggle cycle at each nod position;
(iv) there should be at least two chop cycles per jiggle position.

This gives a maximum of 72 seconds per jiggle. For n = 64, this corresponds to 1.125 seconds maximum per jiggle point - say 1 second to allow some margin. With a minimum of 2 chop cycles per jiggle position, the minimum chop frequency is 2 Hz.

Co-ordination of jiggle and nod cycles: As for FH_POF2.

On-board processing and data rate (see Annex B, *SPIRE Detector Sampling Scheme and Data Rate* for details):
As for FH_POF1.

Instrument and Satellite Functions used and their parameters:

Table TBD: Photometer Observatory Function FH_POF3: n-Point Jiggle Mapping				
Instrument Function: Photometer Chop				
No.	**Parameter**	**Range of values**	**Nominal value**	**Comments**
1	Chop frequency	0.3 (TBC) - 5 Hz	2 (TBC)	Common with FH_POF1.
2	Chop direction	Any direction in the Y-Z plane	Parallel to the Y-axis	Common with FH_POF1.
3	Chop throw	Any value within the BSM range (±2 arcmin. in Y; ±0.25 arcmin in z)	2 arcmin. or greater	Depends on the source size
Instrument Function: Photometer Jiggle				
1	Jiggle pattern	n-point with separation θ n = 16, 32, 64 θ = 2" - 20"	n = 64 θ = TBD	
2	Number of chop cycles/jiggle position	Min = 2 Max = TBD	Such as to give < 72 sec./jiggle cycle	
3	Number of jiggle cycles/nod position	N = 1 - TBD	1	
4	Total integration time	Min = 2 jiggle cycles Max = TBD	None	Only required for nodding OFF
Satellite Function: Nod				
1	Nodding	ON or OFF	ON	
2	Telescope nod period	Min = 3 min Max = TBD	~ 3 min. (TBC)	Determined by the time taken for N jiggle cycles
3	Nod direction	Same as the chop direction	Parallel to the Y-axis	
4	Nod throw	Same as the chop throw	> 2 arcmin	
5	Total number of nod cycles	Min = 2 Max = TBD	TBD	Specifies total integration time if nodding is ON

5.1.4 FH_POF4: Raster Map

Purpose:
This Observatory Function is for mapping a source larger than the SPIRE field of view or to carry out a survey of a large area of sky. It involves jiggle-mapping observations at a grid of telescope pointings. The telescope raster pointing capabilities are described in the *SPMD* (p. 2).

Description:

1. FH_POF4 is composed of the following instrument and Satellite Functions

Instrument Function:Photometer	Chop
	Photometer 7-Point Jiggle
Satellite Functions:	Nod
	Normal Raster Pointing

2. The raster is a rectangular grid of separate pointings as shown in Fig. TBD:

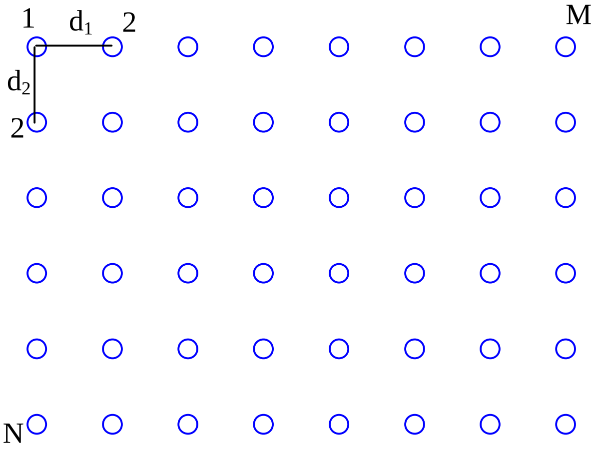


Fig. TBD: Telescope Raster Pointing

The sequence at each point in the raster is exactly as in FH_POF3.

3. For SPIRE, we require the raster axes to be defined not in terms of celestial coordinates, but rather in spacecraft (array) coordinates. This point needs to be discussed with ESA.

4. The astronomer will also wish to specify a region to be mapped in RA and Dec. The relationship between the coordinate frames will depend on exactly when the observations are scheduled. The translation of the astroomer's desired map region into a region suitable for mapping in spacecraft coordinates will need to be done by the ICC.

5. Other issues to be addressed:
Different dwell time at different raster points?
How do we cope with need to calibrate?
Inclusion of calibration FH_POF as possible ingredient of other FH_POFS?

On-board processing and data rate (see Annex B, *SPIRE Detector Sampling Scheme and Data Rate* for details)
As for FH_POF1.

Instrument and Satellite Functions used and their parameters:

Table TBD: Photometer Observatory Function FH_POF4: Raster Mapping

No.	Parameter	Range of values	Nominal value	Comments
Instrument Function: Photometer Chop				
1	Chop frequency	0.3 (TBC) - 5 Hz	2 (TBC)	Common with FH_POF1.
2	Chop direction	Any direction in the Y-Z plane	Parallel to the Y-axis	Common with FH_POF1.
3	Chop throw	Any value within the BSM range (±2 arcmin. in Y; ±0.25 arcmin in z)	2 arcmin. or greater	Depends on the source size
Instrument Function: Photometer Jiggle				
4	Jiggle pattern	n-point with separation θ n = 16, 32, 64 θ = 2" - 20"	n = 64 θ = TBD	
5	Number of chop cycles/jiggle position	Min = 2 Max = TBD	Such as to give < 72 sec./jiggle cycle	
6	Number of jiggle cycles/nod position	N = 1 - TBD	1	
7	Total integration time	Min = 2 jiggle cycles Max = TBD	None	Only required for nodding OFF
Satellite Function: Nod				
1	Nodding	ON or OFF	ON	
2	Telescope nod period	Min = 3 min Max = TBD	~ 3 min. (TBC)	Determined by the time taken for N jiggle cycles
3	Nod direction	Same as the chop direction	Parallel to the Y-axis	
4	Nod throw	Same as the chop throw	> 2 arcmin	
5	Total number of nod cycles	Min = 2 Max = TBD	TBD	Specifies total integration time if nodding is ON
Satellite Function: Normal Raster Pointing				
1	Number of pointings per line (M)	Min = 2 Max = 32		Depends on size of region to be mapped
2	Number of lines (N)	Min = 1 Max = 32		Depends on size of region to be mapped
3	Angular distance between successive steps (d_1)	Min = 2 arcsec. Max = 4 arcmin	Probably in the range 1 - 4 arcmin	Some overlap between successive sub-maps is desirable

4	Angular distance between successive lines (d_2)	Min = 0 or 2 arcsec. Max = 4 arcmin	Probably in the range 1 - 4 arcmin	Some overlap between successive sub-maps is essential

5.1.5 FH_POF5: Scan Map Without Chopping

Purpose:
This Observatory Function is for mapping a large region of sky by scanning the telescope to provide spatial modulation of the signal. This is the preferred observing mode for deep extragalactic surveys. Chopping is not done to avoid increasing confusion noise. The telescope scanning capabilities are described in the *SPMD* (p. 4).

Description:

1. FH_POF5 is composed of the following instrument and Satellite Functions

   Instrument Function: No-Chop
   Satellite Functions: Nod
   Normal Line Scanning

2. The line scans are carried out along parallel lines as shown in Fig. TBD.

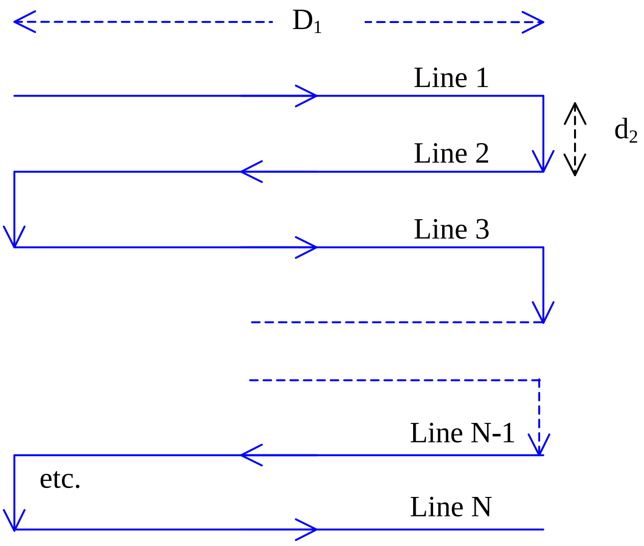


Fig. TBD: Telescope Normal Line Scan Mode (see *SPMD* for full details)

3. Chopping and nodding are not performed.
4. The telescope is scanned continuously across the sky. The spacecraft can scan at rates between 0.1 and 1 arcmin./sec.(*SPMD*, p.8).
5. The scan direction must be in spacecraft coordinates (capability to be confirmed by ESA).
6. For optimum sky sampling, the angle of the scan must have a particular value of 14.5^{o} (TBC) with respect to one of the array axes (Y or Z), as shown in Fig. TBD.

   An alternative arrangement of the detectors in the focal plane could be to orient the lines of detectors at this angle and then to scan exactly along the Z or Y directions.)

7. The length of each line should be such that the turn-around time of the telescope (here assumed to be 10 seconds) does not constitute a large overhead. Each line should therefore take at least 60 seconds.

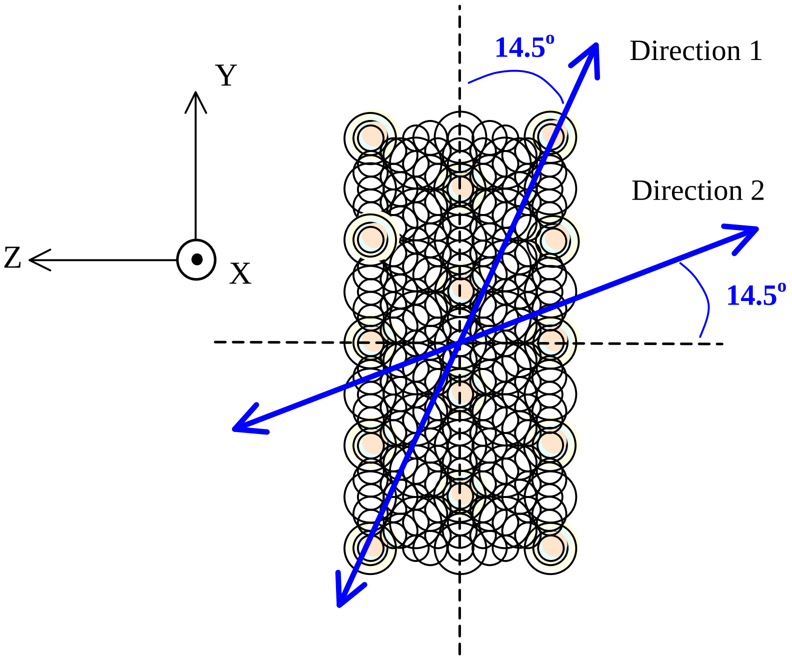


Fig. TBD: Allowed scan directions for Scan Map

Detector sampling:
The demodulated detector signals are to be sampled at 28 Hz with 16-bit resolution.

On-board processing and data rate (see *SPIRE Detector Sampling Scheme and Data Rate*):
The DRCU does no on-board processing. The 16-bit samples are produced at 28 Hz per detector, and are transmitted to the OBDH as part of the SPIRE science data stream for telemetry to the ground. The instantaneous data rate is (28 Hz) x (280 detectors) x (16 bits) = 125.4 kbs. Over a 24-hour period, the average data rate is: (125)*(0.9 observing efficiency)*(22/24 daily efficiency) = 104 kbs. Within the accuracies of the assumed efficiencies, this is consistent with the100 kbs value. The value of 28 Hz could be reduced if necessary with minimal impact on the data quality. The timing of the samples does not need to be synchronised to the telescope movements, but must be available on the ground in order to reconstruct the pointing and generate the maps. This will allow a specific telescope position to be assigned to every detector sample

A "start of scan" marker is needed when the telescope has reached its steady angular velocity.

Instrument and Satellite Functions used and their parameters:

Table TBD: Photometer Observatory Function FH_POF5: Scan Map Without Chopping

Instrument Function: Photometer Non-Chop

No.	Parameter	Range of values	Nominal value	Comments
1	Chopping	OFF	OFF	

Satellite Function: Normal Line Scanning

No.	Parameter	Range of values	Nominal value	Comments
1	Scan direction	Direction 1 or Direction 2 as specified in Fig. TBD	Direction 2 (TBC)	Direction 2 minimises the telescope turn-around overhead
2	Scan rate	Min = 0.1 arcsec./sec. Max = 60"/sec.	60"/sec.	Depends on 1/f noise of the whole system
3	Angular length of each line scan (D_1)	> (60 sec.)*(scan rate) Min = 10 arcmin. Max = 110°		Depends on size of area to be mapped. Unlikely to be > a few degrees.
4	Number of lines (N)	Min = 1 Max = 32		Depends on size of region to be mapped
5	Angular distance between successive steps (d_2)	Min = 2 arcsec. or 0 Max. = 4 arcmin.	Probably in the range 1 - 4 arcmin.	Some overlap between successive sub-maps is essential

5.1.6 FH_POF6: Scan Map With Chopping

Purpose:
This Observatory Function allows for mapping a large region of sky by scanning the telescope with the chopper operating. This mode could be useful in the event of high 1/f noise degrading the S/N for non-chopped scan observations.

Description:

1. FH_POF6 is composed of the following instrument and Satellite Functions

   Instrument Function: Photometer Chop
   Satellite Functions: Nod
   Normal Line Scanning

2. The line scans are carried out as for FH_POF5.
3. Nodding is not performed.
4. Chopping is performed, with a nominal direction parallel to or perpendicular to the direction of the telescope scan.
5. The telescope is scanned continuously across the sky at a rate that provides a beam crossing time much longer than a chop cycle.
6. It is required that the signal from an individual chop cycle be ascribed to an interval of less than 1" on the sky (roughly 1/20th of a beam at 250 μm). The maximum allowed scan rate in "/sec. is then the same as f_{chop} in Hz: e.g., for f_{chop} = 5 Hz, the maximum scan rate is 5"/sec.

Instrument and Satellite Functions used and their parameters:

Table TBD: Photometer Observatory Function FH_POF6: Scan Map With Chopping

No.	Parameter	Range of values	Nominal value	Comments
Instrument Function: Photometer Chop				
1	Chop frequency	0.3 (TBC) - 5 Hz	2 (TBC)	
2	Chop direction	Parallel to or perpendicular to scan direction	TBD	
3	Chop throw	Any value within the BSM range (±2 arcmin. in Y; ±0.25 arcmin in z)	TBD	
Satellite Function: Normal Line Scanning				
1	Scan direction	Direction 1 or Direction 2 as specified in Fig. TBD	Direction 2 (TBC)	Direction 2 minimises the telescope turn-around overhead
2	Scan rate	Min = 0.1 arcsec./sec. Max = 60"/sec.	60"/sec.	Depends on 1/f noise of the whole system
3	Angular length of each line scan (D_1)	> (60 sec.)*(scan rate) Min = 10 arcmin. Max = 110°		Depends on size of area to be mapped. Unlikely to be > a few degrees.
4	Number of lines (N)	Min = 1 Max = 32		Depends on size of region to be mapped
5	Angular distance between successive steps (d_2)	Min = 2 arcsec. or 0 Max. = 4 arcmin.	Probably in the range 1 - 4 arcmin.	Some overlap between successive sub-maps is essential

5.1.7 FH_POF7: Photometer Peak-Up

Purpose:
This Observatory Function is designed to allow SPIRE to peak up the pointing on a sufficiently strong point-like source. As far as the observations are concerned, it is the same as FH_POF3 (7-Point Jiggle Map).

Description:

1. FH_POF6 is composed of the following instrument and Satellite Functions

   Instrument Function: Photometer-Chop
   Satellite Functions: Nod
2. SPIRE does a standard seven-point jiggle observation (FH_POF3).
3. The offset of the source with respect to the commanded pointing is computed by the DRCU using the recorded data.
4. The calculated pointing offsets (ΔY and ΔZ) are transmitted to the spacecraft AOCS.
5. The AOCS checks that the required telescope movement is within the acceptable limits and executes it.
6. The AOCS transmits a message to SPIRE confirming that the pointing correction has been implemented.

   OR

   SPIRE waits for a standard period of time to elapse before flagging the data as valid
7. The need for this function is TBD. It is not needed for very bright objects (carrying out a small map is quick compared to overheads from slewing etc.). Nor is it practical for very faint objects (poor S/N of the 7-point data would lead to inaccurate offset calculation). It is therefore only likely to be useful for a particular band of source strengths (exact limits TBD).
8. The feasibility of this function is TBD. It is not clear whether it will be allowed by ESA. An alternative approach might be to establish an accurate pointing model covering the available sky window by regular observation of a selection of bright point sources, calculating the pointing offsets on the ground, and uplinking the derived pointing model parameters to the spacecraft. This would depend on the availability of good pointing sources distributed over the viewable sky, and on the pointing characteristics being highly repeatable and dependent only on the pointing direction (not on the pointing history).

5.1.8 FH_POF8: Photometer Calibrate

To be written.

Open question: To allow calibration to be performed flexibly, it may be necessary to incorporate this function within some of the other FH_POFS (e.g., to enable calibrator flashes to be interspersed between the rows of line scanning observations).

5.2 Observatory Functions for Spectrometer (Feedhorn Option)

The observatory modes for the FTS will depend on the type of source being observed; point or extended. The FH_POFs have also been separated into low/medium resolution and high resolution to take account of any differences in the on-board processing that might be required.

5.2.1 FH_POF 20: Point Source Spectrum – Low or Medium Resolution

Purpose
To take a spectrum of a point source that is well centred on the middle pixel of the feed horn arrays. The spectrum to be taken has a resolution of no more than R=0.4 cm^{-1} implying a mirror mechanism movement of no more than ±0.32 cm.

Description
This is an example Observatory Function for a resolution of 0.4 cm^{-1}. The distance the FTS mechanism has to scan will be set by the required resolution.

1. This Observatory Function is composed of the following instrument and Satellite Functions:

   Instrument Function: Spectrometer Scan
   Satellite Function: Pointed

2. The telescope is pointed at a known position. This corresponds to the centre pixel of the short-wavelength band array. It is assumed that the centre pixel on each of the two arrays is accurately co-aligned.

3. The FTS calibrator is switched on to a pre-defined level and allowed to stabilise for TBD minutes.

4. The FTS mirror mechanism is scanned from –0.32 cm to +0.32cm with the velocity controlled by the drive electronics. The scan will take about 7 seconds to complete. The detectors and the position sensor are read out asynchronously whilst the mechanism is moving – i.e. the default is to time sample the FTS mechanism position.

5. Each interferogram for each detector is stored in the DPU memory and is a maximum of about 110 kbytes for all 56 detectors if sampled at 12 bits with no data compression. The rate into the DPU is ~16 kbytes/sec.

   Each detector produces a raw interferogram of about 2 kbytes – this could just fit into a single telemetry packet if they were allowed to be this big. Also the proposed loss-less compression may not work as well for these scan ranges as one could never be certain about where one should start throwing away the MSB. This is why I have differentiated between this mode from the high resolution one below.

6. The scan is repeated until the desired integration time has been reached.

Instrument and Satellite Functions used and their parameters:

Table TBD: Spectrometer Observatory Function FH_POF20: Low/Medium Resolution Point Source

No.	Parameter	Range of values	Nominal value	Comments
Instrument Function: Spectrometer Scan				
1	Prime detector	Centre of the two arrays	TBD	This position on the array is aligned on-source for the satellite pointed position
2	Mirror Velocity	0.02-0.1 cm/s – depends on stability of the instrument and the response of the detectors	TBD	
3	Scan Range	Between -0.07 to 0.07 cm (R=2 cm^{-1}) and -0.35 to 0.35 cm (R=0.4 cm^{-1})	N/A	These scan ranges allow some extra range for mirror turn round.
5	Total integration time	Minimum of 3 interferograms for comparison and deglitching	None	The minimum integration time actually on source per pointing is then 5 seconds for the minimum resolution *this is silly given that the calibrator may take some minutes to stabilise! But still……*
Satellite Function: Pointed				
1	Telescope Points to a given position in RA and Dec	N/A	N/A	The satellite is not required to do anything else

5.2.2 FH_POF 21: Point Source Spectrum – High Resolution

Purpose

To take a spectrum of a point source that is well centred on the middle pixel of the feed horn arrays. The spectrum to be taken has a resolution of greater than R=0.4 cm^{-1} implying a mirror mechanism movement from –0.32 cm to as much as 3.2 cm for the full resolution of R=0.04 cm^{-1}.

Description

This is an example Observatory Function for a resolution of 0.04 cm^{-1}. The distance the FTS mechanism has to scan will be set by the required resolution.

1. This Observatory Function is composed of the following instrument and Satellite Functions:

   Instrument Function: Spectrometer Scan
   Satellite Function: Pointed

2. The telescope is pointed at a known position. This corresponds to the centre pixel of the short-wavelength band array. It is assumed that the centre pixel on each of the two arrays is accurately co-aligned.

3. The FTS calibrator is switched on to a pre-defined level and allowed to stabilise for TBD minutes.

4. The FTS mirror mechanism is scanned from –0.32 cm to +3.2cm with the velocity controlled by the drive electronics. The scan will take about 35 seconds to complete. The detectors and the position sensor are read out asynchronously whilst the mechanism is moving – i.e. the default is to time sample the FTS mechanism position.

5. Each interferogram for each detector is stored in the DPU memory and is a maximum of about 575 kbytes for all 56 detectors if sampled at 12 bits with no data compression. The rate into the DPU is ~16 kbytes/sec.

6. The data is compressed using loss-less compression.

   Each raw interferogram will be ~ 10 kbytes per detector – this will have to go across several telemetry packets if it is sent down uncompressed. However it is almost certain that beyond 0.32 cm in the scan range we will not need anything like 12 bits so there is scope for some fairly high degree of data compression here. We will still need to use more than one packet per interferogram per detector.

7. The scan is repeated until the desired integration time has been reached.

Instrument and Satellite Functions used and their parameters:

Table TBD: Spectrometer Observatory Function FH_POF21:
Low/Medium Resolution Point Source

No.	Parameter	Range of values	Nominal value	Comments
Instrument Function: Spectrometer Scan				
1	Prime detector	Centre of the two arrays	TBD	This position on the array is aligned on-source for the satellite pointed position
2	Mirror Velocity	0.02-0.1 cm/s – depends on stability of the instrument and the response of the detectors	TBD	
3	Scan Range	Between –0.35 cm and up to 3.2 cm (R=0.04 cm^{-1})	None	Scan range allows some extra for mirror turn round.
5	Total integration time	Minimum of 3 interferograms for comparison and deglitching	None	The minimum integration time actually on source per pointing is then 108 seconds for the maximum resolution
Satellite Function: Pointed				
1	Telescope Points to a given position in RA and Dec	N/A	N/A	The satellite is not required to do anything else

5.2.3 FH_POF 22: Fully Sampled Spectral Map within FOV – Low/Medium Resolution

Purpose

To take a spectrum of a region of sky or an extended source that is within the FOV of the spectrometer – i.e. less than 2.6 arcmin circular. This is achieved by using the beam steering mirror to perform a jiggle as for the photometer and taking an interferogram at each point of the jiggle pattern. The spectrum to be taken at each point has a resolution of no more than R=0.4 cm^{-1} implying a mirror mechanism movement of no more than ±0.32 cm.

Description

This is an example Observatory Function for a resolution of 0.4 cm^{-1}. The distance the FTS mechanism has to scan will be set by the required resolution.

1. This Observatory Function is composed of the following instrument and Satellite Functions:

   Instrument Function: Spectrometer Scan
   Satellite Function: Pointed

2. The telescope is pointed at a known position. This corresponds to the centre pixel of the short-wavelength band array. It is assumed that the centre pixel on each of the two arrays is accurately co-aligned.

3. The FTS calibrator is switched on to a pre-defined level and allowed to stabilise for TBD minutes.

4. The FTS mirror mechanism is scanned from –0.32 cm to +0.32cm with the velocity controlled by the drive electronics. The scan will take about 7 seconds to complete. The detectors and the position sensor are read out asynchronously whilst the mechanism is moving – i.e. the default is to time sample the FTS mechanism position.

9. The BSM is used to make an n-point jiggle map as in FH_POF-3

5. For full sampling at all wavelengths, n = 25. Considering the simplified case of square-packed horns, the step size must be 0.5λ/D = 9” at 250 μm and the number of steps must accommodate the need to cover the distance between two beams at 350 μm: 2λ/D = 45”. Five steps in each orthogonal direction are thus required. The geometry of the juggle pattern is hexagonal for the hexagonally packed feedhorns, but the number of steps required is still 25. Note that his will result in the map being sparsely sampled at the longest wavelengths.

6. At each jiggle position the FTS miror mechanism is scanned as in point 5. The number of interferograms taken per pointing is TBD a minimum of three would seem sensible. It will take at least 525 seconds to take a fully sampled R=0.4 cm^{-1} 2.6 arcmin circular map – with overheads this will be ten minutes. *(lets hope everything is nice and stable!)*

7. Each interferogram for each detector is stored in the DPU memory and is a maximum of about 110 kbytes for all 56 detectors if sampled at 12 bits with no data compression. The rate into the DPU is ~16 kbytes/sec. The assumption is that there will be no co-addition of the interferograms for each jiggle position.

Each detector produces a raw interferogram of about 2 kbytes – this could just fit into a single telemetry packet if they were allowed to be this big. Also the proposed loss-less compression may not work as well for these scan ranges as one could never be certain about where one should start throwing away the MSB. This is why I have differentiated between this mode from the high resolution one below.

8. The jiggle/scan is repeated until the desired integration time has been reached for the whole map.

Instrument and Satellite Functions used and their parameters:

Table TBD: Spectrometer Observatory Function FH_POF23: Fully Sampled Spectral Map within FOV - Low/Medium Resolution				
Instrument Function: Spectrometer Scan				
No.	**Parameter**	**Range of values**	**Nominal value**	**Comments**
1	Prime detector	Centre of the two arrays	TBD	This position on the array is aligned on-source for the satellite pointed position
2	Mirror Velocity	0.02-0.1 cm/s – depends on stability of the instrument and the response of the detectors	TBD	
3	Scan Range	Between -0.07 to 0.07 cm (R=2 cm^{-1}) and -0.35 to 0.35 cm (R=0.4 cm^{-1})	N/A	These scan ranges allow some extra range for mirror turn round.
Instrument Function: Spectrometer Jiggle				
1	Jiggle pattern	n-point with separation θ n = 25, 64 θ = 2-9"	n = 25 θ = TBD	The number of points could just be fixed as one number – depends on whether its thought a good thing to go for sparse LW band maps?
2	Number of FTS scans jiggle position	Min = 1 Max = TBD	TBD	We need to see whether it is better to go for fully sampled images as fast as possible or to have many FTS scans per jiggle position. depends on the drifts and noise
3	Total integration time	Minimum of 3 interferograms for comparison and deglitching	None	The minimum integration time actually on source per pointing is then 5 seconds for the minimum resolution *this is silly given that the calibrator may take some minutes to stabilise! But still……*
Satellite Function: Pointed				
1	Telescope Points to a	N/A	N/A	The satellite is not required

	given position in RA and Dec			to do anything else

5.3 Observatory functions for Photometer (Filled array Options)

The following modes will be required for the case where there are filled arrays implemented in the in the SPIRE photometer focal plane.

FA_POF1 : Chop Without Microstep (fixed chop size)
FA_POF2 : Optimum Sampling Chop - Harvey
FA_POF3 : Microstep Map
FA_POF4 : Raster Map
FA_POF5 : Scan Map Without Chopping
FA_POF6 : Scan Map With Chopping
FA_POF7 : Operate photometer internal calibrator
FA_POF8 etc. : Special engineering/commissioning modes TBD ??

5.3.1 FA_POF1: Chop Without Microstep

Purpose:
This is similar to the feedhorn option “Chop without Jiggling” (**FH_POF1**), except in the case of the filled arrays using a chop between pixels has no advantage for point source detection; in fact it is probably a very poor way of using the filled arrays. Chopping at a fixed frequency and fixed chop throw will still be required, however, when observing sources that are extended compared to the telescope beam but less than the instrument field of view. In this case chopping, combined with satellite nodding, performs the function of allowing a direct comparison with the nearby sky background and removing any telescope offsets.

The only functional difference between this Observatory Function and **FH_POF1** is that here there is no requirement to chop between co-aligned pixels on the array. This is because it is presumed that, apart from optical aberration and perhaps vignetting close to the edge of the arrays, all parts of all arrays are equivalent in terms of sensitivity.

Description:

1. This Observatory Function is composed of the following instrument and Satellite Functions:

Instrument Function:	Photometer Chop
Satellite Function:	Nod

2. The telescope is pointed at a known position. The position on the sky is aligned with the centre of the shortest wavelength array (TBC); which is defined as the “prime focal plane position” *(or some such……)*.

3. The beam steering mirror implements chopping at frequency f_{chop}.

4. If required, the telescope can also nod at frequency f_{nod}, where $f_{chop} >> f_{nod}$. There is no requirement that f_{nod} be a precise multiple of f_{chop}.

5. The source signal can be computed as the difference between the signals recorded at the two nod positions, as shown in **FH_POF1**. In practice, carrying this procedure out on-board may not be an optimum strategy for the signal recovery and other data compression methods will be

required.

6. Chop distance on the sky: d_{chop} = ±1 Airy disk at shortest wavelength (18 arcsec) to ±2 arcmin (maximum chop throw of the BSM)

Pointing Requirements:
There are no particular requirements on the APE for the filled arrays. The RPE requirements are TBD.

Chopping frequency:
The chopping frequency should be adjustable between frequencies of 0.3 (TBC) and 5 Hz. To simplify the data-processing, a standard set of 6-8 TBD values covering the allowed range could be could be adopted as the nominally available chopping frequencies.

Detector sampling:
The nominal situation is the same as for the feedhorn option i.e. "the demodulated detector signals are to be sampled at 40 Hz with 16-bit resolution." However the actual frame rate will depend on the technology employed for the filled arrays and the number of bits required will only be 14 – see the data rate note in the appendix.

Detector frame sampling rate for the demodulated detector signals	40 Hz (Δt = 0.025 sec)
Number of bits per sample	14
Minimum number of samples per chop half-cycle	4
Minimum chopping period	$T_{min} = 8\Delta t = 0.2$ sec
Maximum chopping frequency	$1/T_{min} = 5$ Hz
Minimum chopping frequency	0.313 Hz (TBC)
Nominal chopping frequency	1.25 Hz (TBC)

Table 5.2-: Details of detector sampling and chopping frequency for filled arrays

Synchronisation of the chopper and detector readout:
The chopper movement and the sampling must be synchronised so that the data are not sampled while the chopper is in motion between the two positions. It is proposed that this be ensured by the use of a flag generated from the BSM position servo: sampling of each half cycle begins at a specified time T after the BSM position reached flag has been produced. *Once again this all needs some more thought - for the filled arrays the optimum method of reading out the frames may not be to attempt to synchronise the frame read to the chopper but to read at a higher rate and select or average the samples to achieve the net 40 Hz.*

Sampling of all detectors will not be simultaneous. Question: How should the samples be interleaved?

Chopping and data sampling are carried out continuously, even while the telescope is moving from one nod position to another, and do not need to be synchronised with the telescope motions. Identification of the data corresponding to the transitions will be done on the ground using the telescope pointing history.

On-board processing and data rate (see Annex B, *SPIRE Detector Sampling Scheme and Data Rate* for details)

There are 3712 pixels to be read out for the filled arrays. If the nominal 40 Hz final sampling rate were averaged over each chop half cycle and then the chop half cycles differenced *(bad)* the telemetry rate would be 199 kbs (see data rate note). Even this would require some serious data compression to come within the allocated 100 kbs. The likelihood is that there will need to be some fairly sophisticated on board processing to reduce the data rate – probably averaging chop half cycles or some-such.

Instrument and Satellite Functions used and their parameters:

Table TBD: Photometer Observatory Function FA_POF1: Chop Without Microstep

No.	Parameter	Range of values	Nominal value	Comments
		Instrument Function: Photometer Chop		
1	"Prime" detector	Centre of the shortest wavelength array (TBC)	TBD	This position on the array is aligned on-source for nod position 1
2	Chop frequency	0.3 (TBC) - 5 Hz	TBD	
3	Chop direction	Any direction in the Y-Z plane	Parallel to the Y-axis	
4	Chop throw	Any value within the BSM range (±2 arcmin. in Y; ±0.25 arcmin in z)	126" on the sky parallel to Y-axis	
5	Total integration time	Min = 10 chop cycles Max = TBD	None	Only required for nodding OFF
		Satellite Function: Nod		
1	Nodding	ON or OFF	ON	Nodding is optional
2	Nod period	Any value within allowed range	3 minutes	The SPMD does not give complete information on the ranges of chop amplitude and frequencies that are possible. A nominal figure of 3 minutes for the total nod cycle time is appropriate for SPIRE.
3	Nod direction	Same as the chop direction	Parallel to the Y-axis	
4	Nod throw	Same as the chop throw	126"	
5	Total number of nod cycles	Min = 2 Max = TBD	None	Specifies total integration time if nodding is ON

5.3.2 FA_POF2: Optimum Sampling Chop

Purpose:
This is an observation strategy that will optimally sample the FOV of the instrument using as many different "scale lengths" across the detectors as possible. In this manner any gain; straylight or noise variations across the array of any scale length are correctly sampled and can be optimally removed (is this its only purpose?). In execution it will look like a chopped observation with a variable chop throw and direction. *(Are these statements right – Harvey suggested it?)*

Description:

1. This Observatory Function is composed of the following instrument and Satellite Functions:

   Instrument Function: Photometer Variable Chop
   Satellite Function: Nod

2. The telescope is pointed at a known position. The position on the sky is aligned with the centre of the shortest wavelength array (TBC); which is defined as the "prime focal plane position" *(or some such……)*.

3. The beam steering mirror starts variable position chopping. That is it moves at time intervals commensurate with some chop frequency f_{chop} but to a variety of positions at different distances across the FOV.

4. If required, the telescope can also nod at frequency f_{nod}, where $f_{chop} >> f_{nod}$. There is no requirement that f_{nod} be a precise multiple of f_{chop}.

5. The integration time can either be built up by multiple samples at each chop cycle distance – i.e. five chops at 18 arcsec in one direction; five at 72 arcsec in another etc. Or by doing multiple complete sequences.

6. Chop distance on the sky for each sample may be between ±1 Airy disk at shortest wavelength (18 arcsec) to ±2 arcmin (maximum chop throw of the BSM) and may be in any direction – the direction may/will be different for each chop cycle.

Pointing Requirements:
As for **FA_POF1**

Chopping frequency/positions:
The most likely scenario, if this observation is implemented, is to have a pre-determined and fixed set of positions to chop to with only the chop frequency variable. As in the other chop modes a limited set of chop frequencies would be made available.

Detector sampling:
The same comments apply to this observation as for **FA_POF1**

Synchronisation of the chopper and detector readout:
As for **FA_POF1**

On-board processing and data rate (see Annex B, *SPIRE Detector Sampling Scheme and Data Rate* for details)
As for **FA_POF1**

Instrument and Satellite Functions used and their parameters:
All highly speculative – we need much more information on this observation from Harvey and/or its proponents.

Table TBD: Photometer Observatory Function FA_POF2: Optimal Sampling Chop

No.	Parameter	Range of values	Nominal value	Comments
Instrument Function: Photometer Variable Chop				
1	"Prime" detector	Centre of the shortest wavelength array (TBC)	TBD	This position on the array is aligned on-source for nod position 1
2	Chop frequency	0.3 (TBC) - 5 Hz	TBD	
3	Chop direction	Pre-determined set of positions	TBD	
4	Chop throw	Variable for each chop cycle to any value within the BSM range (±2 arcmin. in Y; ±0.25 arcmin in z)	TBD	
5	Total integration time	Min = TBD Max = TBD	None	Specifies total integration time if nodding is OFF
Satellite Function: Nod				
1	Nodding	ON or OFF	ON	Nodding is optional
2	Nod period	Any value within allowed range	TBD	The SPMD does not give complete information on the ranges of chop amplitude and frequencies that are possible. A nominal figure of 3 minutes for the total nod cycle time is appropriate for SPIRE.
3	Nod direction	Any direction	Parallel to the Y-axis	
4	Nod throw	Any allowable distance	TBD	
5	Total number of nod cycles	Min = 2 Max = TBD	None	Specifies total integration time if nodding is ON

5.3.3 FA_POF3: Microstep Map

This observation allows the instrument FOV to be moved across the detectors in steps that are small compared to the pixel size. In this way the FOV is "super sampled" in a way that, it is predicted, will allow deconvolution techniques to be applied that will achieve point source location and a recovery better than the inherent spatial resolution of the instrument.

The typical step size will 1/5 pixel and the typical total movement will be up to a few pixels across the array. The beam may also be copped at the same time – either using **FA_POF1** or **FA_POF2 –** and the satellite may also be nodded to remove telescope backgrounds.

Description:

1. This Observatory Function is composed of the following instrument and Satellite Functions:

Instrument Function:	Photometer Microstep Photometer chop or Photometer Optimum Sampling chop

Satellite Function: Nod

2. The telescope is pointed at a known position. The position on the sky is aligned with the centre of the shortest wavelength array (TBC); which is defined as the "prime focal plane position" *(or some such……)*.
3. The beam steering mirror is stepped by 1/5 of a pixel (TBC).
4. The beam steering mirror may then be used to chop the beam from this position – either using Photometer Chop or Photometer Variable Chop.
5. The satellite may be nodded with or without the chopping function.
6. The beam steering mirror is stepped to by another 1/5 pixel and the cycle repeated up to the required distance – up to a few pixels at the longest wavelength.
7. The total integration time for the observation is built up by many repeated sequences.

Pointing Requirements:
In order that this observation is useful, the pointing stability will need to be better than some small fraction of a pixel (1/5 – better?) over the integration time of the observation – some tens of minutes? There are no absolute pointing requirements.

Chopping frequency/positions:
If chopping is used then for each microstep there will be a number of chop cycles – either with **FA_POF1** or **FA_POF2**. The complete sequence of step-chop-step…..chop up to the end of the movement range will be completed before the satellite is nodded. The nod position will be arbitrary.

Detector sampling:
The same comments apply to this observation as for **FA_POF1**

Synchronisation of the chopper and detector readout:
As for **FA_POF1**

On-board processing and data rate (see Annex B, *SPIRE Detector Sampling Scheme and Data Rate* for details)
As for **FA_POF1**

Instrument and Satellite Functions used and their parameters:

Table TBD: Photometer Observatory Function FA_POF3: Microstep Map

Instrument Function: Photometer Chop

No.	Parameter	Range of values	Nominal value	Comments
1	Prime detector	Centre of the shortest wavelength array (TBC)	TBD	Common with FA_POF1
2	Chop frequency	0.3 (TBC) - 5 Hz	2 (TBC)	Common with FA_POF1
3	Chop direction	Any direction in the Y-Z plane	Parallel to the Y-axis	Common with FA_POF1
4	Chop throw	Any value within the BSM range (±2 arcmin. in Y; ±0.25 arcmin in z)	126" on the sky parallel to Y-axis	Common with FA_POF1

Instrument Function: Photometer Variable Chop

No.	Parameter	Range of values	Nominal value	Comments
1	“Prime” detector	Centre of the shortest wavelength array (TBC)	TBD	Common with FA_POF2
2	Chop frequency	0.3 (TBC) - 5 Hz	TBD	Common with FA_POF2
3	Chop direction	Pre-determined set of positions	TBD	Common with FA_POF2
4	Chop throw	Variable for each chop cycle to any value within the BSM range (±2 arcmin. in Y; ±0.25 arcmin in z)	TBD	Common with FA_POF2
5	Total integration time	Min = TBD Max = TBD	None	Specifies total integration time if nodding is OFF

Instrument Function: Photometer Microstep

No.	Parameter	Range of values	Nominal value	Comments
1	Step Size	Any up to the maximum movement of the BSM	1/5 pixel on the shortest wavelength array ~1.6 arcsec	
2	Movement range	Any up to the maximum movement of the BSM	One Airy disk of the longest wavelength array ~ 36 arcsec	
3	Number of chop cycles/jiggle position	Min = 5 Max = TBD	Such as to give roughly 1 minute per jiggle cycle	
4	Number of microstep cycles/nod position	N = 1 – TBD	1	
5	Total integration time	Min = 1 microstep cycle Max = TBD	None	Only required for nodding OFF

Satellite Function: Nod				
No.	**Parameter**	**Range of values**	**Nominal value**	**Comments**
1	Nodding	ON or OFF	ON	Nodding is optional
2	Telescope nod period	Determined by the time taken for N microstep cycles	Set to allow one microstep cycle per nod position	
3	Nod direction	Any	Parallel to the Y-axis	
4	Nod throw	Any	None	
5	Total number of nod cycles	Min = 2 Max = TBD	TBD	Specifies total integration time if nodding is ON

5.3.4 FA_POF4: Raster Map

Purpose:
This Observatory Function is for mapping a source larger than the SPIRE field of view or to carry out a survey of a large area of sky. It involves jiggle-mapping observations at a grid of telescope pointings. The telescope raster pointing capabilities are described in the *SPMD* (p. 2).

Description:

1. FA_POF4 is composed of the following instrument and Satellite Functions

Instrument Function:	Photometer Chop or Variable
	Photometer Microstep
Satellite Functions:	Nod
	Normal Raster Pointing

2. The raster is a rectangular grid of separate pointings as shown in Fig. TBD (above):
   The sequence at each point in the raster is exactly as in FA_POF1; FA_POF2 or FA_POF3, depending on which is chosen as the optimum mapping strategy.

3. For SPIRE, we require the raster axes to be defined not in terms of celestial coordinates, but rather in spacecraft (array) coordinates. This point needs to be discussed with ESA.

4. The astronomer will also wish to specify a region to be mapped in RA and Dec. The relationship between the coordinate frames will depend on exactly when the observations are scheduled. The translation of the astronomer's desired map region into a region suitable for mapping in spacecraft coordinates will need to be done by the ICC.

5. Other issues to be addressed:
   Different dwell time at different raster points?
   How do we cope with need to calibrate?
   Inclusion of calibration FH_POF as possible ingredient of other FH_POFS?

On-board processing and data rate (see Annex B, *SPIRE Detector Sampling Scheme and Data Rate* for details)
As for FA_POF1.

Instrument and Satellite Functions used and their parameters:

Table TBD: Photometer Observatory Function FA_POF4: Raster Mapping

Instrument Function: Photometer Chop				
No.	**Parameter**	**Range of values**	**Nominal value**	**Comments**
1	Prime detector	Centre of the shortest wavelength array (TBC)	TBD	Common with FA_POF1
2	Chop frequency	0.3 (TBC) - 5 Hz	2 (TBC)	Common with FA_POF1
3	Chop direction	Any direction in the Y-Z plane	Parallel to the Y-axis	Common with FA_POF1
4	Chop throw	Any value within the BSM range (±2 arcmin. in Y; ±0.25 arcmin in z)	126" on the sky parallel to Y-axis	Common with FA_POF1
Instrument Function: Photometer Variable Chop				
No.	**Parameter**	**Range of values**	**Nominal value**	**Comments**
1	"Prime" detector	Centre of the shortest wavelength array (TBC)	TBD	Common with FA_POF2
2	Chop frequency	0.3 (TBC) - 5 Hz	TBD	Common with FA_POF2
3	Chop direction	Pre-determined set of positions	TBD	Common with FA_POF2
4	Chop throw	Variable for each chop cycle to any value within the BSM range (±2 arcmin. in Y; ±0.25 arcmin in z)	TBD	Common with FA_POF2
5	Total integration time	Min = TBD Max = TBD	None	Specifies total integration time if nodding is OFF
Instrument Function: Photometer Microstep				
No.	**Parameter**	**Range of values**	**Nominal value**	**Comments**
1	Step Size	Any up to the maximum movement of the BSM	1/5 pixel on the shortest wavelength array ~1.6 arcsec	Common with FA_POF3
2	Movement range	Any up to the maximum movement of the BSM	One Airy disk of the longest wavelength array ~ 36 arcsec	Common with FA_POF3
3	Number of chop cycles/jiggle position	Min = 5 Max = TBD	Such as to give roughly 1 minute per jiggle cycle	Common with FA_POF3
4	Number of microstep cycles/nod position	N = 1 – TBD	1	Common with FA_POF3

5	Total integration time	Min = 1 microstep cycle Max = TBD	None	Only required for nodding OFF
Satellite Function: Nod				
No.	**Parameter**	**Range of values**	**Nominal value**	**Comments**
1	Nodding	ON or OFF	ON	Nodding is optional
2	Telescope nod period	Determined by the time taken for N microstep cycles	Set to allow one microstep cycle per nod position	
3	Nod direction	Any	Parallel to the Y-axis	
4	Nod throw	Any	None	
5	Total number of nod cycles	Min = 2 Max = TBD	TBD	Specifies integration time per point if nodding is ON
Satellite Function: Normal Raster Pointing				
1	Number of pointings per line (M)	Min = 2 Max = 32		Depends on size of region to be mapped
2	Number of lines (N)	Min = 1 Max = 32		Depends on size of region to be mapped
3	Angular distance between successive steps (d_1)	Min = 2 arcsec. Max = 4 arcmin	Probably in the range 1 - 4 arcmin	Some overlap between successive sub-maps is desirable
4	Angular distance between successive lines (d_2)	Min = 0 or 2 arcsec. Max = 4 arcmin	Probably in the range 1 - 4 arcmin	Some overlap between successive sub-maps is essential

5.3.5 FA_POF5: Scan Map Without Chopping

Purpose:
This Observatory Function is for mapping a large region of sky by scanning the telescope to provide spatial modulation of the signal. This is the preferred observing mode for deep extragalactic surveys. Chopping is not done to avoid increasing confusion noise. The telescope scanning capabilities are described in the *SPMD* (p. 4).

Description:

1. FA_POF5 is composed of the following instrument and Satellite Functions

   Instrument Function: No-Chop
   Satellite Functions: Normal Line Scanning

2. The line scans are carried out along parallel lines as shown in Fig. TBD (above).

3. Chopping and nodding are not performed.
4. The telescope is scanned continuously across the sky. The spacecraft can scan at rates between 0.1 and 1 arcmin./sec.(*SPMD*, p.8).
5. The scan direction must be in spacecraft coordinates (capability to be confirmed by ESA).

6. The angle of the scan can be either along the Y or Z axis of the spacecraft.
7. The length of each line should be such that the turn-around time of the telescope (here assumed to be 10 seconds) does not constitute a large overhead. Each line should therefore take at least 60 seconds.

Detector sampling:
The demodulated detector signals are to be sampled at 28 Hz with 16-bit resolution.

On-board processing and data rate (see *SPIRE Detector Sampling Scheme and Data Rate*):
The DRCU will average four 28 Hz samples down to the net sampling rate of 7 Hz. This will give 322 kbs. To fit this within the 100 kbs there will need to be some large degree of data compression. Possible methods of achieving this are discussed in the appendix on the data rate.

A "start of scan" marker is needed when the telescope has reached its steady angular velocity.

Instrument and Satellite Functions used and their parameters:

Table TBD: Photometer Observatory Function FA_POF5: Scan Map Without Chopping

Instrument Function: Photometer Non-Chop				
No.	**Parameter**	**Range of values**	**Nominal value**	**Comments**
1	Chopping	OFF	OFF	Looks STANDBY mode BSM off
Satellite Function: Normal Line Scanning				
1	Scan direction	Direction 1 or Direction 2 as specified in Fig. TBD	Direction 2 (TBC)	Direction 2 minimises the telescope turn-around overhead
2	Scan rate	Min = 0.1 arcsec./sec. Max = 60"/sec.	60"/sec.	Depends on 1/f noise of the whole system
3	Angular length of each line scan (D_1)	> (60 sec.)*(scan rate) Min = 10 arcmin. Max = 110^o		Depends on size of area to be mapped. Unlikely to be > a few degrees.
4	Number of lines (N)	Min = 1 Max = 32		Depends on size of region to be mapped
5	Angular distance between successive steps (d_2)	Min = 2 arcsec. or 0 Max. = 4 arcmin.	Probably in the range 1 - 4 arcmin.	Some overlap between successive sub-maps is essential

5.3.6 FA_POF6: Scan Map With Chopping

Purpose:
This Observatory Function allows for mapping a large region of sky by scanning the telescope with the chopper operating. This mode could be useful in the event of high 1/f noise degrading the S/N for non-chopped scan observations.

Description:

1. FA_POF6 is composed of the following instrument and Satellite Functions

Instrument Function:	Photometer Chop Photometer Variable Chop
Satellite Functions:	Normal Line Scanning

2. The line scans are carried out as for FA_POF5
3. Nodding is not performed.
4. Chopping or Variable Chopping is performed, with a nominal direction parallel to or perpendicular to the direction of the telescope scan.
5. The telescope is scanned continuously across the sky at a rate that provides a beam crossing time much longer than a chop cycle.
6. It is required that the signal from an individual chop cycle be ascribed to an interval of less than 1" on the sky (roughly 1/20th of a beam at 250 µm). The maximum allowed scan rate in "/sec. is then the same as f_{chop} in Hz: e.g., for f_{chop} = 5 Hz, the maximum scan rate is 5"/sec.

Instrument and Satellite Functions used and their parameters:

Table TBD: Photometer Observatory Function FA_POF6: Scan Map With Chopping

Instrument Function: Photometer Chop

No.	Parameter	Range of values	Nominal value	Comments
1	Chop frequency	0.3 (TBC) - 5 Hz	2 (TBC)	
2	Chop direction	Parallel to or perpendicular to scan direction	TBD	
3	Chop throw	Any value within the BSM range (±2 arcmin. in Y; ±0.25 arcmin in z)	TBD	

Instrument Function: Photometer Variable Chop

No.	Parameter	Range of values	Nominal value	Comments
1	Chop frequency	0.3 (TBC) - 5 Hz	2 (TBC)	
2	Chop direction	Parallel to or perpendicular to scan direction	TBD	
3	Chop throw	Variable for each chop cycle to any value within the BSM range (±2 arcmin. in Y; ±0.25 arcmin in z)	TBD	

Satellite Function: Normal Line Scanning

1	Scan direction	Direction 1 or Direction 2 as specified in Fig. TBD	Direction 2 (TBC)	Direction 2 minimises the telescope turn-around overhead
2	Scan rate	Min = 0.1 arcsec./sec. Max = 60"/sec.	60"/sec.	Depends on 1/f noise of the whole system
3	Angular length of each line scan (D_1)	> (60 sec.)*(scan rate) Min = 10 arcmin. Max = 110°		Depends on size of area to be mapped. Unlikely to be > a few degrees.
4	Number of lines (N)	Min = 1 Max = 32		Depends on size of region to be mapped
5	Angular distance between successive steps (d_2)	Min = 2 arcsec. or 0 Max. = 4 arcmin.	Probably in the range 1 - 4 arcmin.	Some overlap between successive sub-maps is essential

5.4 Observatory Functions for Spectrometer (Filled Array Options)

These will be the same as for the feedhorn option except we may not use the jiggle – or microstepping as it would be for the filled arrays. Keep it in as maybe some people may want to make super high resolution spatial/spectral maps and we may have to do it if we lose some detectors.

The only thing that changes for the filled arrays is how the data are dealt with. There have to be decimation and data compression in order to get the stuff within the 100 kbs *see note on FTS operation.*

6. DEGRADED OPERATIONS

Description of possible degradations in instrument capabilities – loss of part or whole of an array; loss or partial loss of BSM; loss or partial loss of FTS mech.; limited cooling power etc.

This section is under consideration – for the time being refer to the note on the System Level Failure Assessment SPIRE-RAL-NOT-000319 where the type of backup modes that will be required is identified if not the actual detail.

7. INSTRUMENT FUNCTIONS

7.1 Required Instrument Functions

Table of all the instrument functions identified in previous sections.

7.2 Instrument Function Descriptions

Description of each Instrument Function
Sub-system operations and synchronisation
Data stream

7.3 Instrument Data Configurations

Description of typical data configurations
Description of sampling required

APPENDIX A: DATA RATES

SPIRE Detector Sampling Scheme and Data Rate

Matt Griffin and Bruce Swinyard

DRAFT 13 July

1. INTRODUCTION

This note is an updated version of the draft circulated on 24 March. It has been prepared following the splinter meeting at the PDR on July 9, as input to the Warm Electronics Group meeting on July 19, 20.

It summarises the assumptions we currently make about data sampling and the estimated telemetry rate requirements.

The baseline data rate available to each of the FIRST instruments has recently been specified by ESA as 100 kbs (averaged over a 24 hr period) - see PT-06885. There may be some flexibility on this number (e.g., by increasing the downlink time over the nominal 2 hours at the expense of observing time if a larger amount of data needs to be transmitted).

For the purposes of this note, we assume the following:

Available average data rate per 24-hr period = 100 kbs
Length of observing period = 22 hours

2. PHOTOMETER

2.1 Assumptions for photometer

- Nominal case: filled arrays with 0.5Fλ pixels (worst case for data rate).
- 4 x 8 arcminute field of view
- Filled array sizes are 32 x 64; 24 x 48 and 16 x 32 pixels at 250, 350, and 500 μm respectively
- DC coupling - so we need enough dynamic range to digitise the noise on top of the large offset from the telescope background power (which will always be greater than the power received by the

detectors from even a strong source).

- No deglitching on board, but glitches may be flagged or else detected on the ground through searching for outliers, or both. It is assumed that flagging glitches does not add significantly to the data rate.

- We require 2 bits to digitise the noise

- The effective detector sampling rate = 40 Hz. The instantaneous value may be higher, but the samples are averaged down to this level before being passed to the DRCU processing routine that deals with generating the numbers to be telemetered to the ground.

2.2 Number of bits needed for telemetry to the ground

Based on these assumptions, the required number of bits per sample *for telemetry to the ground* is 13 for filled array detectors and 14 for feedhorn detectors. Briefly this is arrived at as follows:

	Filled	**Feedhorn**
- Telescope background power on 250 μm detector (pW)	2	8
- Overall NEP for 250 μm detector (W $Hz^{-1/2}$)	7×10^{-17}	14×10^{-17}
- Signal bandwidth of detectors (Hz)	20	20
- Biggest signal we'll ever digitise and telemeter (pW)	1	4
- This is the NET signal from the strongest source we can observe (~1500 Jy at 250 μm).		
- Dynamic range required to digitise the net signal is:		

Filled:
$$\frac{(2)(1 \times 10^{-12})}{7 \times 10^{-17}\sqrt{20}} = 6.39 \times 10^{3} \equiv 12.6 \text{ bits - call it 13}$$

Feedhorn:
$$\frac{(2)(4 \times 10^{-12})}{14 \times 10^{-17}\sqrt{20}} = 1.28 \times 10^{4} \equiv 13.6 \text{ bits - call it 14}$$

2.3 Number of bits needed for detector sampling

The required number of bits per sample *for the ADC that samples the detector signals* is 15 for filled array detectors and 16 for feedhorn detectors. This is calculated arrived as follows:

When sampling the detectors, if we want to digitise the noise we actually need to digitise all the way to the GROSS signal (telescope + source). We assume, pessimistically, that we would need to do this even in the presence of the strongest source signal i.e. we sum the telescope signal and the net signal from the strongest source in the table above. So we require

Filled
$$\frac{(2)(3 \times 10^{-12})}{7 \times 10^{-17}\sqrt{20}} = 1.92 \times 10^{4} \equiv 14.2 \text{ bits - call it 15}$$

Feedhorn $\frac{(2)(12\,\mathrm{x}\,10^{-12})}{14\,\mathrm{x}\,10^{-17}\sqrt{20}}$ = 3.8 x 10^4 ≡ 15.2 bits - call it 16

We recommend that the raw detector signals are digitised to 16 bits and only after subtraction of the chop cycles (see below) converted to 13 bits (if filled arrays) or 14 bits (if feedhorn arrays).

Note: we do not specify anything about the *instantaneous* sampling rate of the detectors or what intermediate operations need to be carried out on the raw detector data in order to get it into the form of 16-bit numbers generated at 40 Hz per detector. **It is up to the array groups to specify what needs to be done here so that the DRCU processing power can be estimated.**

2.4 Uncompressed data rates for the photometer

2.4.1 Chopping

We assume

- Chopping at 5 Hz (the maximum rate)
- Effective sampling at 40 Hz (i.e., 4 samples per chop half-cycle)
- Averaging of each half-cycle on board to produce effective 10 Hz sampling rate
- For each full chop cycle, computation of the difference between half-cycles on board and transmission of this to the ground at a rate of 5 numbers per detector per second.
- Observing efficiency = 90%

The effective data rate is then :
5 samples per detector per second
x 3712 or 280 detectors (filled or feedhorn)
x 13 or 14 bits per sample(filled or feedhorn)
x 0.9 observing efficiency
x 22/24 fraction of 24 hrs used
= **199 or 16 kbs (filled or feedhorn)**

In the case of the feedhorns, it would be appropriate to transmit all the 16-bit samples taken at 5 Hz, with a telemetry rate of 5 x 280 x 16 x 0.9 x 22/24 = 18.5 kbs.

Surely we would not do the differencing for the feedhorns so the rate would be at least 10 Hz if not the full 40 Hz – i.e. send it all down and fill the available telemetry so either 10x280x16x22/24 = 37 kbs or 40x280x16x0.9x22/24 = 148 kbs and then compression on this

2.4.2 Scanning

We assume that:

- The telescope is scanned continuously across the sky. The maximum scan rate is 1 arcmin/sec.(*FIRST Scientific Pointing Modes,* p8). We therefore assume a scan rate of 60 arcsec/sec.

The FWHM beams on the sky are approximately 18, 25 and 36 arcsec. at 250, 350 and 500 μm respectively. The minimum beam crossing times are therefore 0.30, 0.42 and 0.60 sec.

- We must telemeter a minimum of two samples per FWHM, corresponding to sampling intervals of 0.15, 0.21 and 0.30 sec. or 6.7, 4.8 and 3.3 Hz.

It would be convenient to sample all of the arrays at the same frequency, so we assume the worst case of 7 Hz sampling for all three arrays. This can be made up of averages of four measurements with the detectors sampled at 28 Hz

- The net telemetry rate will be		7	samples per detector per second
		3712 or 280	detectors (filled or feedhorn)
	x	15 or 16	bits per sample (filled or feedhorn)
	x	0.9	observing efficiency
	x	22/24	fraction of 24 hours used
	=	**322 or 26 kbs**	**(filled or feedhorn)**

In the case of the feedhorns, it would be appropriate to transmit all the 16-bit samples taken at 28 Hz, with a telemetry rate of 28 x 280 x 16 x 0.9 x 22/24 = 103 kbs.

2.5 Options for reducing the photometer telemetry rate

The uncompressed average telemetry rates for the filled arrays are greater than the 100 kbs figure that ESA have allocated. Options for reducing the telemetry rate are:

1. Chop mode:

   Chop more slowly and so average on board over a longer period. Reducing the chop frequency from 5 to to 2.5 Hz while still averaging over each chop half-cyclye would reduce the uncompressed data rate to 100 kbs. As long as the 1/f noise threshold of the detectors permits this, it should not be a problem, although it is not so good for deglitching.

   Average frames in chopping mode (not desirable as it will mix glitches in with good data).

2. Scan mode:

   Scan the telescope more slowly and effectively average for longer on each sample of the FWHM. If we scan at, say, 20 arcsec/sec, then we can telemeter three times more slowly, and just about live with 100 kbs. This would involve an effective sampling rate of 7/3 = 2.3 Hz, so we'd have to be sure that1/f noise would not be coming in at this level.

   Average more samples per FWHM in the 350 and 500 μm channels, since the beam is bigger. We could reduce the effective sample frequency to 5 and 3.5 samples for 350 and 500 μm, respectively, which would reduce the uncompressed telemetry rate to

   (0.9)(22/24)(15)(7 x 2048 + 5 x 1152 + 3.5 x 512) = 271 kbs

So this saves 50 kbs at the expense of sampling the three arrays at different frequencies, which is not very elegant.

3. All modes:

Implement some form of lossless compression. There will be a large degree of redundancy in the data due, for example, to the following:

- Chop mode: the difference recorded for a chop cycle will change slowly from one chop cycle to the next because several cycles will always be done with the detector looking in the same direction.

- Scan mode: With at least two samples per FWHM, the astronomical signal even from a point source (delta function on the sky) will not change by more than a factor of 2 between samples.

- Scan mode: We are not differencing on board, so the majority of the undifferenced signal will just be the telescope offset (at least two thirds, even for the very strongest sources to be observed, and much more for the vast majority of sources).

Thus there could be scope for **substantial lossless compression of the data**. It seems likely that putting the time series signal from an individual detector through some standard lossless compression algorithm could produce a lossless compression by a large factor.

2.6 Conclusions and questions for the photometer

2.6.1 Conclusions

In chopping mode, a telemetry rate of about 200 kbs would allow us to transmit individual “photometer frames” (a frame here is defined as the result of an ON-OFF subtraction of one 0.2-second chopper cycle, for the full 4 x 8 field of view) with no deglitching and no frame averaging on board.

If we slow down the chopper by a factor of two or average over two half cycles, then we can fit into 100 kbs.

For scanning at 60 arcsec/sec. a telemetry rate of 270-320 kbs would allow us to transmit all the scan mode data with no loss of fidelity owing to averaging glitched and good data.

If we scan three times more slowly, then we can just fit in to 100 kbs

If lossless compression by a factor of 2-3 can be achieved, then we can chop or scan at the maximum rates and still be within the 100 kbs limit.

For the feedhorn option, there is no problem with 100 kbs for any mode, and the actual samples can be telemetered.

Not quite true

2.6.2 Questions

1. How can we estimate what this achievable compression factor is likely to be?
2. Can we design the system so that the necessary processing is done in software? That would make the system maximally flexible and enable us to adapt the compression scheme to the actual flight conditions and observing modes to achieve maximum efficiency and to prevent an inappropriate (or maybe useless) scheme being hard-wired into the system. (It is difficult to predict exactly how we may want to operate the system seven years from now!)

3. Could compression be done with a general purpose algorithm implemented in the DRCU processor, or would we need to write a special algorithm ourselves?

4. What level of processing power is likely to be needed to implement such compression on board?

3. FTS

3.1 Assumptions

- There is only one operating mode for the FTS - scanning the mirror mechanism whilst the telescope is kept at a fixed pointing.

- Baseline FTS operating parameters as in BMS note of 3 Mar 99 which updated the previous case for the selected Mach-Zehnder design - briefly the assumptions are:

  Filled arrays (worst case for data rate) - one array of 16x16 and one array of 12x12 - 400 detectors
  Detectors assumed to have 20 Hz 3-dB frequency and are sampled at 200 Hz for the 16x16 array and 133 Hz for the 12x12 array - 70 kHz total rate.
  If there is no nulling of the telescope background we will require 16-bit sampling
  If the telescope background is nulled to 5% we will require only 12 bits
  Assume 90% observing efficiency (for telescope slewing, scan dead-time, etc.).

- The instantaneous data rate - no decimation, no overhead - will be 1120 kbs for 16-bit sampling and 840 kbs for 12-bit sampling. This is what will pass from the detector read-out into whatever electronics is responsible for the interferogram processing.

- The processor will have to perform the deglitching and decimation of the interferogram back to critical sampling. After decimation and allowing for overheads, the rate for telemetry to the ground will be:

  (1120*0.9*22/24)/5 = 185 kbs for 16 bit sampling

  and

  (840*0.9*22/24)/5 = 139 kbs for 12 bit sampling

- For 12 bit sampling and full decimation we can almost meet the 100 kbs rate. Some compromises are possible: slow down the mirror; observe at lower data rate for fraction of the orbit; assume some lossless compression.

- For the feedhorn option we assume there will be 56 detectors. The maximum *instantaneous data rate before decimation* is therefore 130 kbs for 16 bit sampling and 97 kbs for 12 bit sampling.

- For the filled array options, a 1/5 duty cycle for SPIRE would allow us to transmit raw data as a special engineering mode.

- If desired, we could also transmit raw data from a few detectors (e.g., the central pixels)

3.2 Conclusions:

1. We are close to meeting the 100 kbs budget if we assume that we can null the telescope background to within 5%. However, for the filled arrays, this means that we will be entirely reliant on the calibration source working correctly.
2. We recommend that a 16 bit ADC is implemented and, unless the calibrator fails, only 12 bits are telemetered. This means that the instantaneous data transfer rate will be of order 1200 kbs from the detector readout to the on-board processor responsible for the decimation.
3. No averaging of interferograms should be implemented - we will cope with any restrictions on the data rate in other ways - lossless compression etc.
4. If the feedhorn option is chosen there will be no requirement for on-board processing of the interferograms.

APPENDIX B: OBSERVING SEQUENCES

Descriptions of typical observing sequences required to carry out the scientific programme

APPENDIX C: SCIENTIFIC POINTING MODES