SPIRE

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

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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. Keep data rate in appendix? No put into a separate document and reference this.

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, with PACS as PRIME and SPIRE operating in PARALLEL mode (see minutes of FST5). SPIRE can also operate in SERENDIPITY mode, taking data while the telescope is slewing.

2.2.1 Mission Operations

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

- FIRST will operate autonomously with no real time monitoring of the telemetry on the ground except during the data transfer periods.
- FIRST will be out of ground contact for 21 out of every 24 hours.
- When the spacecraft is out of ground contact, 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).
- 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 safe mode in the event of a detected anomaly in the DPU operation.
- Nominal ground contact will be for 3 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 24 hours of operations will be uplinked.
- 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.

2.2.2 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 OBSERVATORY FUNCTIONs with parameters for the SPACECRAFT FUNCTIONs; INSTRUMENT FUNCTIONs and INSTRUMENT DATA CONFIGURATIONs that make up the OBSERVATORY FUNCTIONs. 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 and DATA CONFIGURATIONS which, with the appropriate input parameters, allow any OBSERVATION to be carried out.

- **Spacecraft Functions:** These are the operations that can be carried by the spacecraft 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. Spacecraft 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; 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 CHOP START or READ PHOTOMETER FRAME that allow the instrument controllers to build any required INSTRUMENT FUNCTIONS without resort to low level commands.

- **Instrument Commands:** This is the low level command language used to control the instrument (Note change name in diagram)

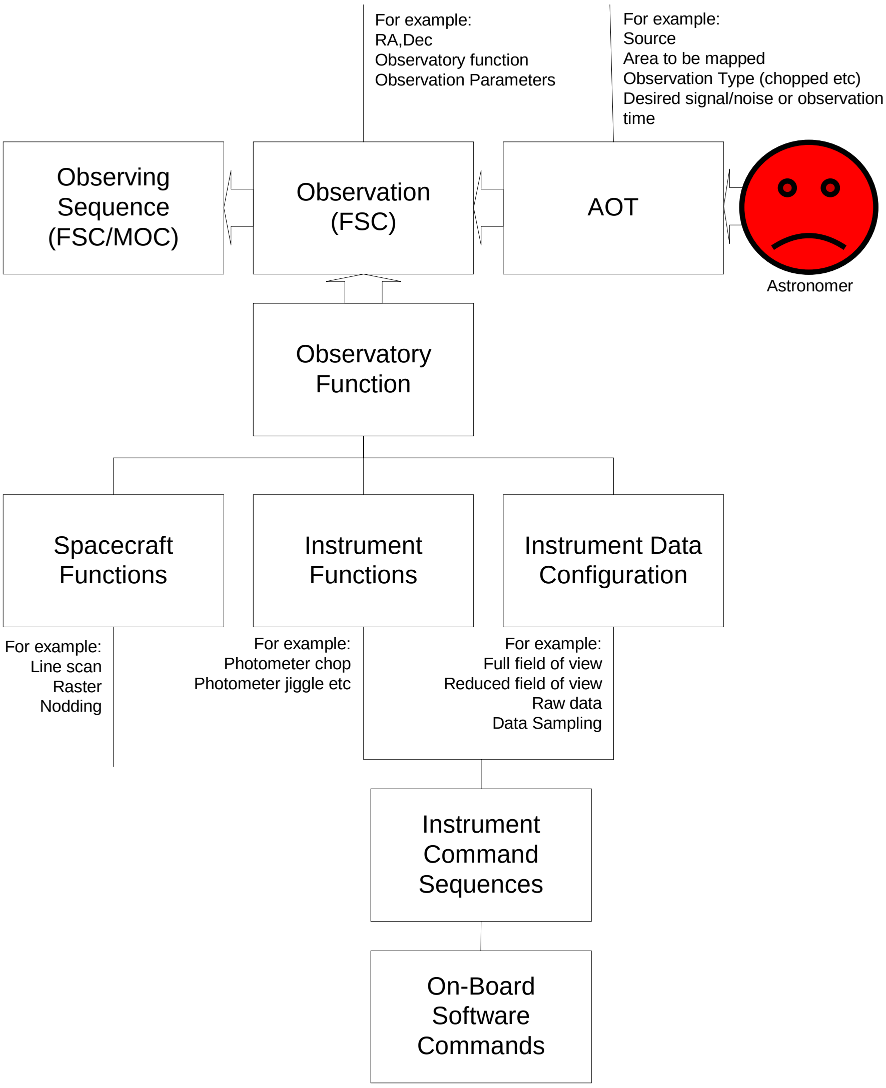


Figure 2.1: Diagrammatic representation of the connection between the various elements for the implementation of the SPIRE Observe Mode

2.3 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.

2.3.1 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. Relevant information is in the IID-A.

2.3.2 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 Fig. 2-2.

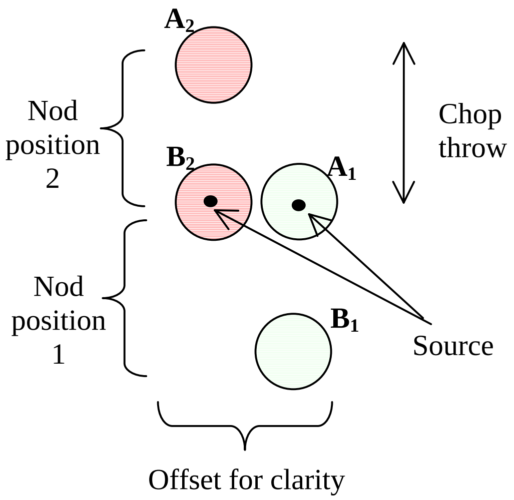


Figure 2.2: Pointing positions for a telescope NOD function. The circles represent the size of the telescope Airy pattern projected onto the sky. The two nod positions have been offset left and right for clarity. In reality A_1 and B_2 would be co-aligned

2.3.3 Raster

The RASTER Spacecraft 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.

2.3.4 Line Scan

In the LINE SCAN Spacecraft 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.

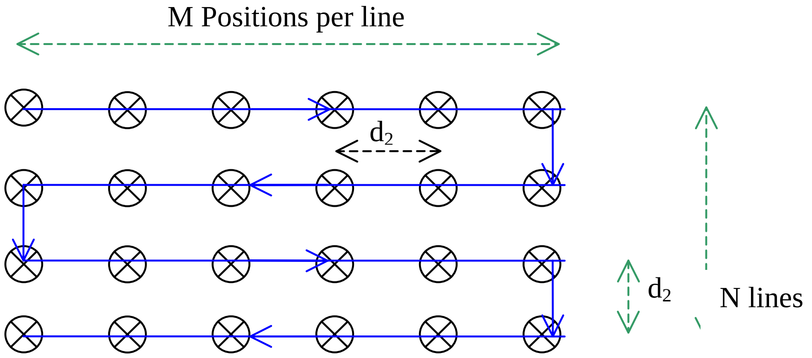


Figure 2.3: Pointing positions for a telescope RASTER function. The observation is specified in terms of M pointings per line separated by d_1 by N lines separated by d_2 arcsec.

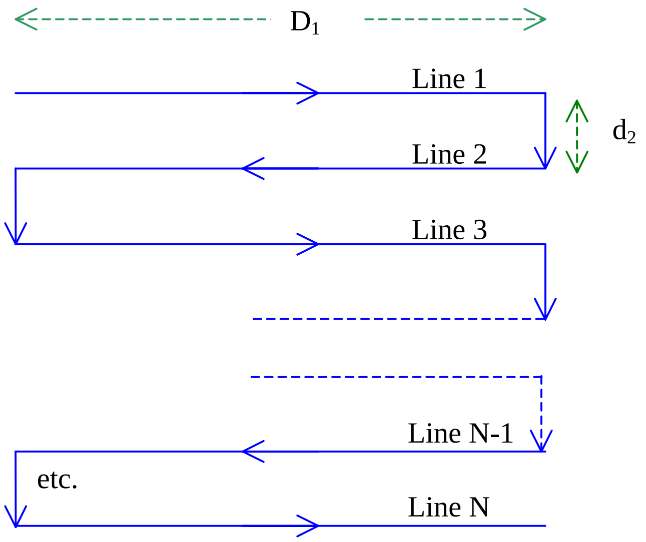


Figure 2.4: The LINE SCAN function of the telescope consists of a number of short slews of length D_1 separated by a distance d_2. The slews will be carried out in the order shown here

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 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.

3.3 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.

3.4 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 (CREC) 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).
(Note change name in diagram)

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 shows the logical transition from one operating mode to another.
(Change diagram to refelect new WE configuration – no software in DRCU anymore)

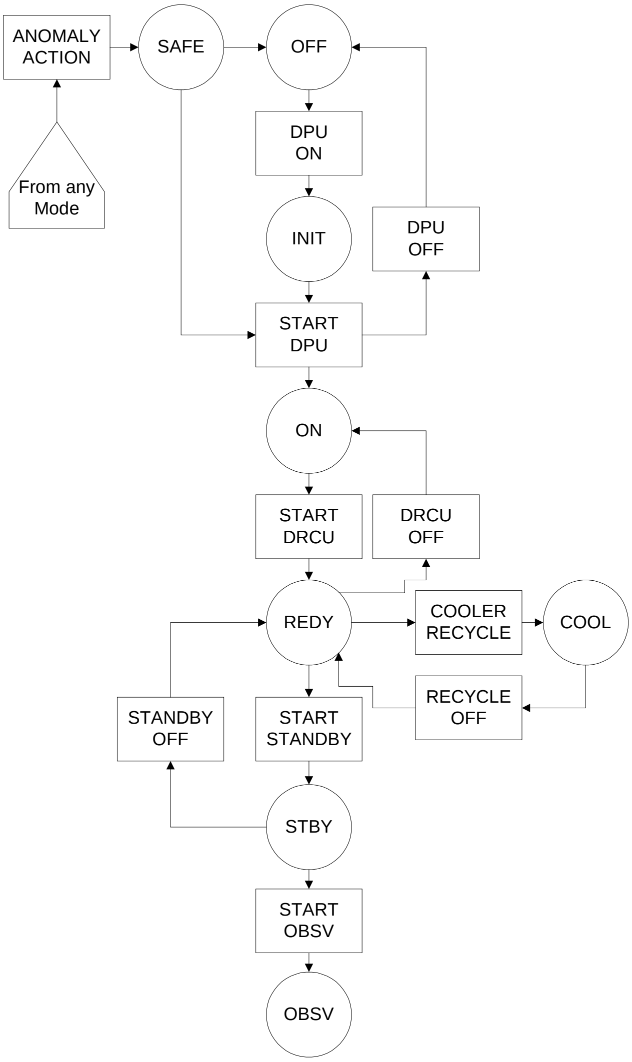


Figure 3.1: Logical transition flow between SPIRE operating modes. The boxes represent instrument command sequences to switch a mode on. (Naming convention is UNIT_VERB – change to START and STOP for modes and ON and OFF for units)

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: 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: 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 4.3: 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 4.4: Expected data configurations and telemetry rates for all operating modes except OBSV. All figures are TBC.

4.4 Spacecraft 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 Spacecraft 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 Spacecraft 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 generated 4. Confirmation of DPU status from DPU housekeeping	INIT
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	REDY

Initial Instrument State	Procedures	Events/verification	Final Instrument State
		4. Confirmation of DCRU status from DRCU housekeeping	
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: 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 are switched off from DRCU housekeeping	REDY
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 4.6: 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 4.7: 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 4.8 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 4.8: 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.

5.1 Telescope pointing

[This will be moved up to Section 2] It is assumed that SPIRE pointing will be defined with respect to the telescope boresight by two offset positions, one for the centre of the photometer arrays and one for the centre of the spectrometer arrays, as shown below. When the telescope is pointed at a source at the request of SPIRE, it shall be aligned on one of the two positions defined in Fig. 5.1 below. Any offsetting by the SPIRE BSM or the AOCS shall then be defined with respect to this position.

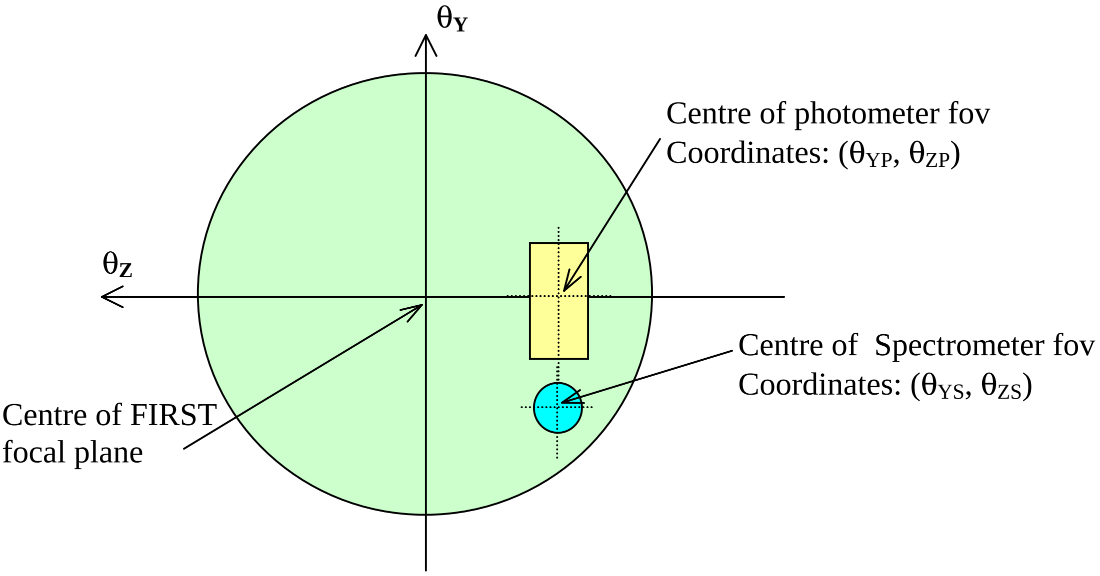


Figure 5.1: Definition of SPIRE pointing offsets with respect to the telescope boresight.

5.1.1 Pointing errors

The FIRST/Planck IID-A provides the following information on the telescope pointing accuracy.

Absolute Pointing Error (APE): The angular separation between the commanded direction and the instantaneous actual direction.

Pointing Drift Error (PDE): The angular separation between the short time average (barycentre of the actual pointing during some time interval) and a similar average pointing at a later time. The drift is given over 24 hours during the same observation period.

Relative Pointing Error (RPE): The angular separation between the instantaneous orientation of the satellite fixed axis at some time t and a reference axis (average, barycentre) over defined period. This is also known as the pointing stability.

Attitude Measurement Error (AME): The angular separation between the actual and the measured orientation of the satellite fixed axis defined instantaneously. This performance requirement is referred to as "a posteriori knowledge".

Absolute Rate Error (ARE) : The angular rate separation between the actual and the controlled angular rate about the satellite spin axis.

APE:	Required	3.7”	Goal	1.5"
RPE (1 min pointing)	Required	0.3"	Goal	0.3"
RPE (1 min scanning)	Required	1.2"	Goal	0.8"
AME (pointing)	Required	3.1"	Goal	1.2"
AME (scanning)	Required	5.0"	Goal	1.4"
AME (slewing)	Required	10"	Goal	1.5"

These figures are specified at a temporal probability level of 68% (i.e., the error will be within the specified value for more than 68% of the time).

5.2 Observatory Functions for the Photometer

The Observatory Functions for the photometer are listed below

Observatory Function	Name	Comments
POF1	Chop without jiggling	Point source; accurate pointing
POF2	Seven-point jiggle map	Point source; inaccurate pointing
POF3	n-point jiggle map	Field mapping
POF4	Raster map	Extended field mapping
POF5	Scan map without chopping	Large-area mapping
POF6	Scan map with chopping	Large area mapping (with 1/f noise)
POF7	Photometer peak-up (TBD)	Determination of pointing offsets
POF8	Operate photometer internal calibrator	
POF9	Special engineering/commissioning modes (TBD)	

Table 5.1: Photometer Observatory Functions

5.3 Signal modulation and detector sampling

The following considerations apply to several of the photometer Observatory Functions.

5.3.1 Chopping frequency and detector sampling

The chopping frequency will be adjustable between frequencies of 0.2 (TBC) and 5 Hz. Values greater than 2 Hz are not baselined for operation, and will only be used as a degraded mode in the event of high 1/f noise. 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. The sampling parameters for the demodulated detector signals and the allowed chopping frequencies are summarised below.

Minimum detector frame sampling rate	20 Hz (TBC)
Maximum detector frame sampling rate	30 Hz (TBC)
Nominal detector frame sampling rate	24 Hz (TBC)
Number of bits per sample	16
Nominal chopping frequency range	0.2 Hz (TBC) - 2 Hz
Maximum chopping frequency	2 Hz (TBC) *

* 5 Hz for degraded mode operation.

Table 5.2: Details of detector sampling and chopping frequency

The exact chop frequency will be set by defining the sampling rate and the number of samples to be taken at each BSM position.

5.3.2 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. Chopping and data sampling can be 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. BSM movement and detector sampling will be synchronised as follows:

- Timing of the BSM movements and detector sampling are based on commanding from the DPU

- The detectors are sampled continuously at an even rate - nominally 24 Hz (Δt = 41.7 ms).
- Immediately after the last sample at a BSM position, the command to move the BSM is issued
- An integral number of samples is obtained at the new BSM position
- The initial sample(s) may coincide with BSM motion or detector settling, but in a repeatable manner

The figure below shows schematically the detector waveform and its sampling.

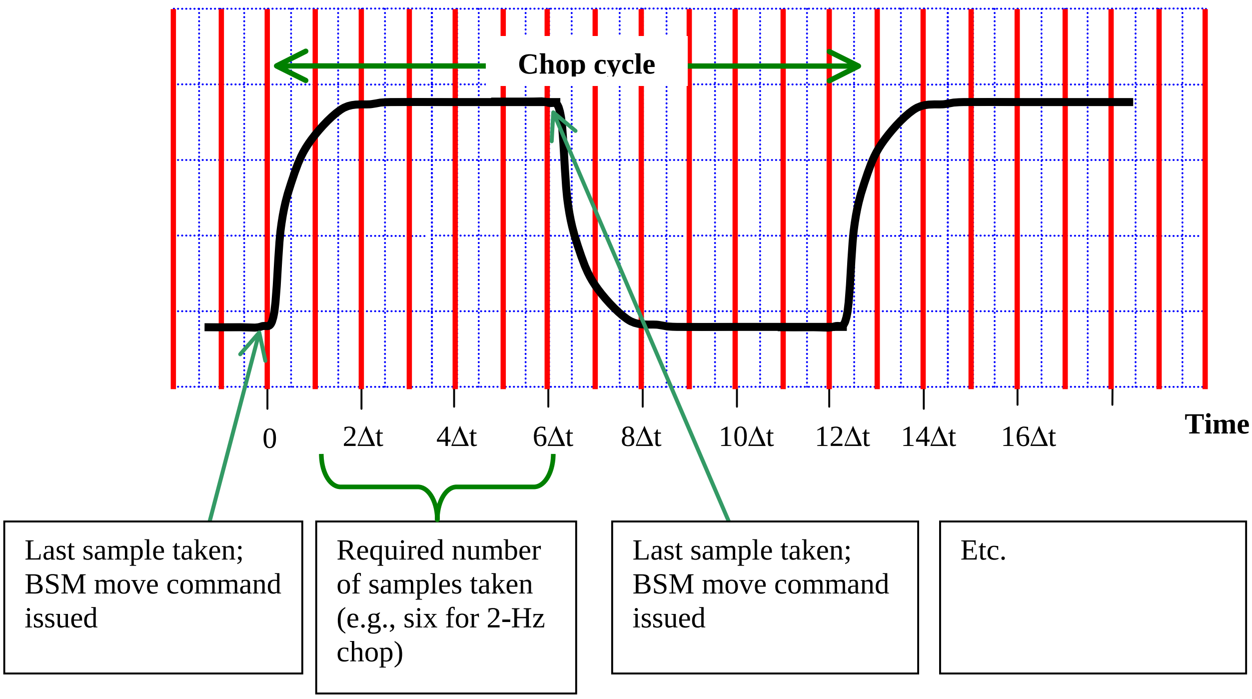


Figure 5.2: Timeline of demodulated detector output and sampling grid for the case of a 2-Hz chop and 25 Hz sampling rate.

Questions:

- What jitter is allowed?
- Sampling of the 280 detectors will not be exactly instantaneous. How long does it take to sample the whole set of detectors (all three arrays)? Is this time long or short compared to the sampling interval?

5.3.3 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 readout rate is very much larger than the chop frequency).* All the 16-bit samples taken at 25 Hz, are transmitted to the OBDH as part of the SPIRE science data stream for telemetry to the ground. The instantaneous data rate is (25 Hz) x (280 detectors) x (16 bits) = 112 kbs. Over a 24-hour period, the average data rate is: (112)*(0.9 observing efficiency)*(22/24 daily efficiency) = 92 kbs, which fits within the 100 kbs limit. If the effective science data rate is less than 100 kbs, then the solution is to decrease the sampling frequency or to discard some samples on board before telemetry.

5.3.4 POF1: Chop Without Jiggling

Purpose:
This 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 one detector of the feedhorn array. In the case of SPIRE, chopping is done between two sets of three detectors that are co-aligned on the sky so that simultaneous observations are done in the three bands with maximum efficiency.

Description:

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

Instrument Function:	Photometer Chop
Spacecraft Function:	Nod

2. The telescope is pointed at the commanded position, which is aligned with the centre of the arrays.

3. In nominal operation, the BSM chops symmetrically at f_{chop} about this position in the Y-direction, moving the source alternately onto the two sets of three co-aligned detectors near the centre of the arrays- see Figure 5.1-1. Chopping in a direction not parallel to the Y-axis will be possible, but not normally used.

4. If required, the telescope can also nod at frequency f_{nod}, where $f_{chop} >> f_{nod}$. There is no requirement that fnod be a precise multiple of fchop. A value of > 1 minute and < 4 minutes per nod cycle is appropriate, otherwise the telescope settling time overhead (10-18 seconds) will become prohibitive or the nod time will become excessive. At present, we assume a nominal value of 3 minutes.

5. The source signal is computed as the difference between the signals recorded at the two nod positions, as shown in Fig 5.1-1. 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.

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

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

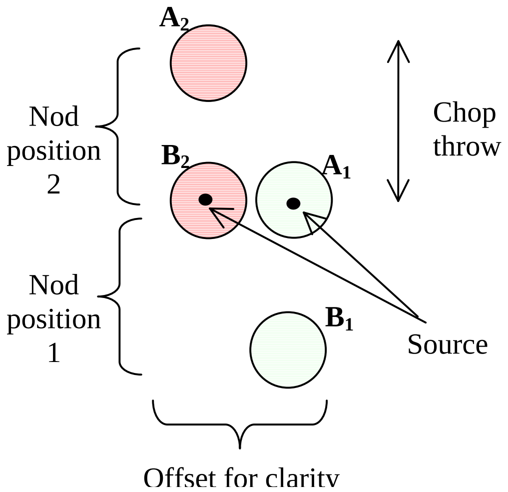


Figure 5.3: Telescope nodding to cancel out differences in the background power on the detector in the two chop positions.

6. Chopping between pairs of pixels gives maximum sensitivity because in that case the source is being observed all the time. There is simultaneous overlap at all three wavelengths for 14 sets of detectors, 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).

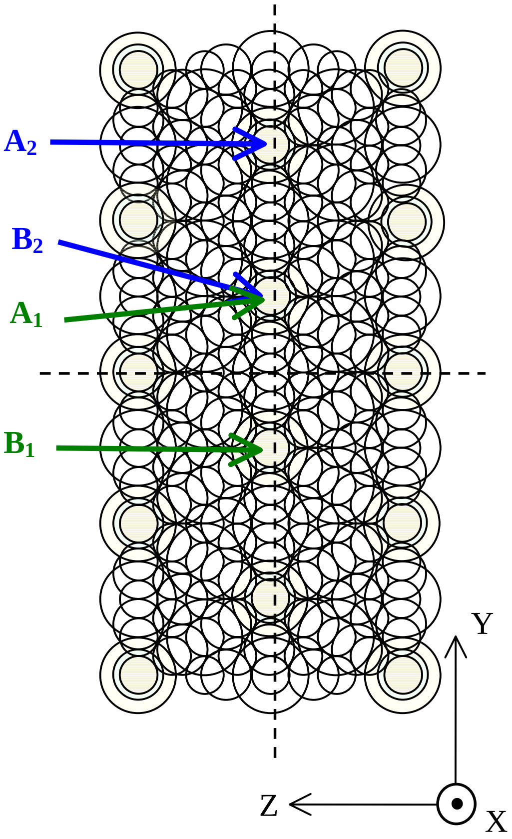


Figure 5.4: Sets of detectors (shaded) for which there is simultaneous overlap in all three bands for the feedhorn array option. For chopped observations, one of the sets nearest the centre of the array is used as to define the prime pointing direction.

7. Chop distance on the array: $d_{chop} = 4F\lambda$ 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.

8. 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: θ_{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.

9. This mode requires pointing accuracy sufficiently good that the loss of signal due to the pointing error is acceptable. The signal loss factors for the photometer beams are shown below.

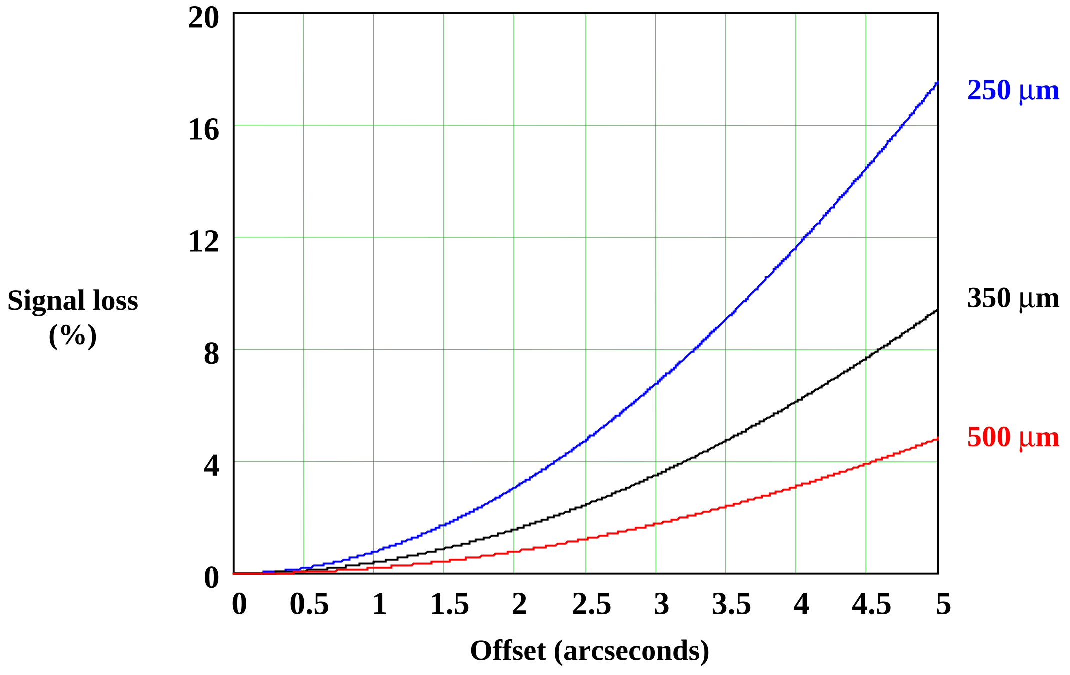


Figure 5.5: Signal loss vs. pointing error for the SPIRE photometer

10. The required APE (3.7") corresponds to 11%, 6%, 3% signal loss at 250, 350, 500 μm respectively. The goal (1.5") corresponds to 2 %, 1%, 0.5% signal loss at 250 350, 500 μm respectively. For most observations, 11% is not acceptable, but 2% is. Therefore, 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 (POF7).

Instrument and Spacecraft Functions used and their parameters:

<table>
<tr><th colspan="5">Table 5.3 Photometer Observatory Function POF1: Chop Without Jiggling</th></tr>
<tr><th colspan="5">Instrument Function: Photometer Chop</th></tr>
<tr><th>No.</th><th>Parameter</th><th>Range of values</th><th>Nominal value</th><th>Comments</th></tr>
<tr><td>1</td><td>Chop frequency</td><td>0.2 (TBC) - 2 Hz</td><td>2 Hz in Y</td><td>Max frequency is 1 Hz in the Z direction or any compound Y-Z angle</td></tr>
<tr><td>2</td><td>Chop direction</td><td>Any direction in the Y-Z plane</td><td>Parallel to the Y-axis</td><td>Max frequency is 1 Hz in the Z direction or any compound Y-Z angle</td></tr>
<tr><td>3</td><td>Chop throw</td><td>Any value within the BSM range (±2 arcmin. in Y; ±0.25 arcmin in z)</td><td>126" (±63") on the sky parallel to Y-axis</td><td></td></tr>
<tr><td>4</td><td>Total integration time</td><td>Min = 4 hop cycles
Max = TBD</td><td>None</td><td>Only required if not nodding</td></tr>
<tr><th colspan="5">Spacecraft Function: Nod</th></tr>
<tr><td>1</td><td>Nodding</td><td>ON or OFF</td><td>ON</td><td>Nodding is optional</td></tr>
<tr><td>2</td><td>Nod period</td><td>Any value within allowed range</td><td>3 minutes</td><td>The SPMD does not give complete information on the ranges of nod amplitude and frequencies that are possible. A nominal figure of 3 minutes for the total nod cycle time is appropriate for SPIRE.</td></tr>
<tr><td>3</td><td>Nod direction</td><td>Same as the chop direction</td><td>Parallel to the Y-axis</td><td></td></tr>
<tr><td>4</td><td>Nod throw</td><td>Same as the chop throw</td><td>126"</td><td></td></tr>
<tr><td>5</td><td>Total number of nod cycles</td><td>Min = 1
Max = TBD</td><td>None</td><td>Specifies total integration time if nodding</td></tr>
</table>

5.3.5 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 POF1.

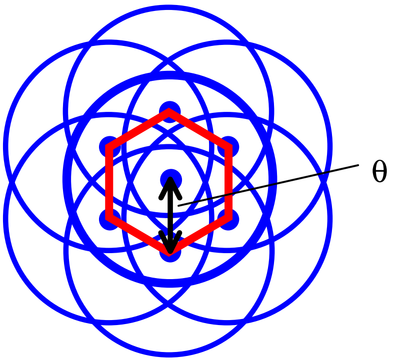
Description:

1. POF2 is composed of the following instrument and Spacecraft Functions:

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

2. The BSM is used to do to do small map 7-point hexagonal jiggle map with spacing θ arcsec., as shown 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.

Figure 5.6 : 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 0.5Fλ, 1.0Fλ and 2.0Fλ 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 2 chop cycles are required at each jiggle position. The minimum dwell time is therefore in the range 1 second (for f_{chop} = 2 Hz) and 15 seconds (for f_{chop} = 0.2 Hz). As a nominal case, we shall adopt f_{chop} = 2 Hz and 20 chop cycles. 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

SPIRE will be allowed to control the timing of the telescope nodding motions - these will be pre-programmed in the daily up-link of the observing sequences. The nod period should therefore be predetermined to provide an integer number of complete jiggle cycles at each nod position.

On-board processing and data rate: As POF1.

Instrument and Spacecraft Functions used and their parameters:

Table 5.4: Photometer Observatory Function POF2: Seven-point jiggle map

Instrument Function: Photometer Chop				
No.	**Parameter**	**Range of values**	**Nominal value**	**Comments**
1	Chop frequency	As for POF 1		
2	Chop direction	As for POF1		
3	Chop throw	As for POF1		
Instrument Function: Photometer Jiggle				
1	Jiggle pattern	7-point (central + hexagon) with angular separation θ	θ = 6 arcsec.	
2	Number of chop cycles/jiggle position	Min = 2 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
Spacecraft Function: Nod				
1	Nodding			
2	Nod period	Determined by the time taken for N jiggle cycles	Set to allow one jiggle cycle per nod position	
3	Nod direction	As for POF1		
4	Nod throw	As for POF1		
5	Total number of nod cycles	As for POF1		

5.3.6 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 POF2.

Description:

1. POF3 is composed of the following instrument and Spacecraft Functions:

Instrument Function:	Photometer Chop Photometer n-Point Jiggle
Spacecraft 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. The maximum throw is 4 arcminutes (± 2 arcminutes) as illustrated below.

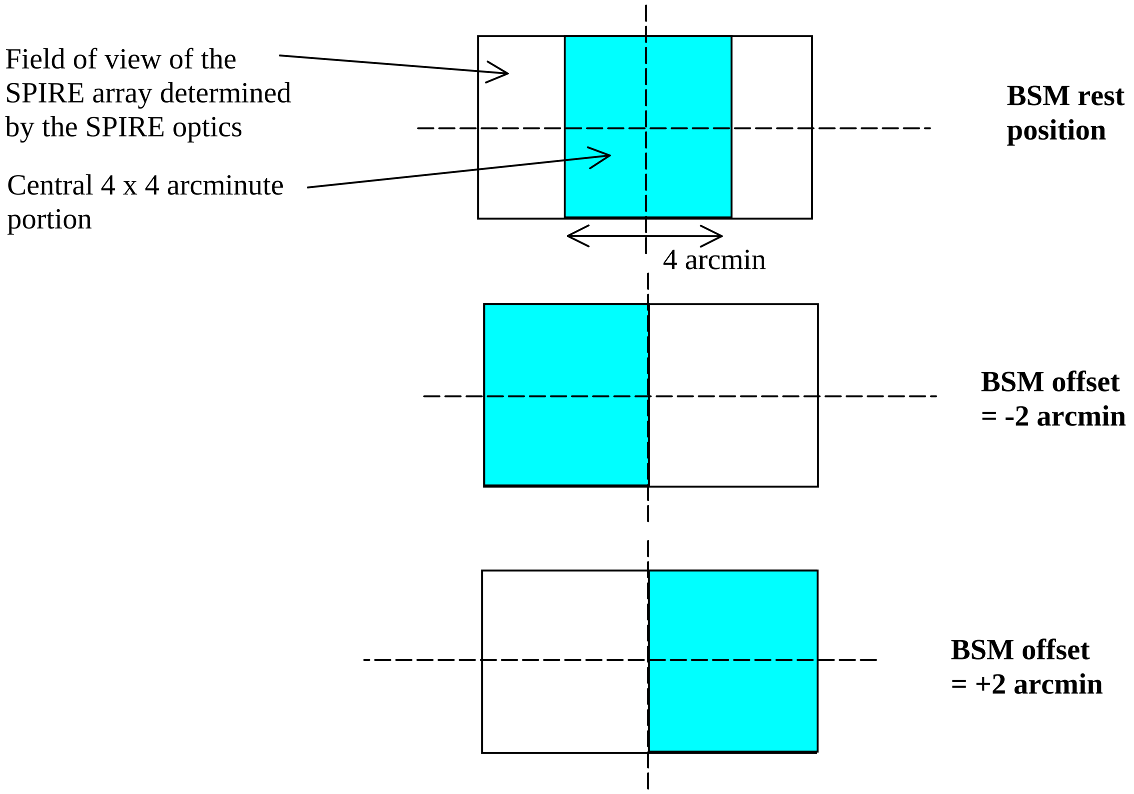


Figure 5.7: Field mapping with maximum chop throw of 4 arcminutes. The detectors in the central square 2 x 2 arcminute portion of a photometer array are deflected by ± 2 arcminutes by the BSM, so that they are alternately chopped from one side of the available field of view to the other.

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 jiggle positions shall be defined by angles $\Delta\theta_Y$ and $\Delta\theta_Z$ in the Y and Z directions (with respect to the BSM rest position).

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

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

8. Nodding is optional.

9. 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 18 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. This can be done with 2 chop cycles per jiggle position at the maximum chop frequency of 2 Hz.

Co-ordination of jiggle and nod cycles: As for POF2.

On-board processing and data rate: As for POF1.

Instrument and Spacecraft Functions used and their parameters:

Table 5.5: Photometer Observatory Function POF3: n-Point Jiggle Map

No.	Parameter	Range of values	Nominal value	Comments
Instrument Function: Photometer Chop				
1	Chop frequency	As for POF1		
2	Chop direction	As for POF1		
3	Chop throw	As for POF1	±2 arcmin. (chopping the full field)	
Instrument Function: Photometer Jiggle				
1	Jiggle pattern	n-point with positions ($\Delta\theta_Y$,$\Delta\theta_Z$) with respect to the pointed position n = 16, 32, 64	n = 64 ($\Delta\theta_Y$,$\Delta\theta_Z$) are TBD	
2	Number of chop cycles/jiggle position	Min = 2 Max = TBD		
3	Number of jiggle cycles/nod position	N = 1 (TBC)	1	
4	Total integration time for the map	Min = 2 jiggle cycles Max = TBD	None	Only required for nodding OFF
Spacecraft 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	As for POF1		
4	Nod throw	As for POF1		
5	Total number of nod cycles	As for POF1		

5.3.7 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. POF4 is composed of the following instrument and Spacecraft Functions

Instrument Function:	Photometer Chop
	Photometer n-Point Jiggle
Spacecraft Functions:	Nod (optional) (Is this really necessary? – may be difficult to implement)
	Normal Raster Pointing

2. The available field is the central 4 x 4 arcminute portion of the array.

3. The raster is a rectangular grid of separate pointings as shown in Section 2. The sequence at each point in the raster is exactly as in n-Point Jiggle Map (POF3).

4. The astronomer will 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 co-ordinates poses a problem for the efficient implementation of this mode.

   For SPIRE, we require the raster axes to be defined not in terms of celestial coordinates, but rather in spacecraft (array) coordinates. This needs discussion – the problem here is that the observer would not know how long the observation was until it was scheduled – it may be better to define a smaller FOV for rasters and use RA and Dec to specify the map area – use a diagram to define this……

5. Other issues to be addressed:
   For long rasters, it may be necessary to interleave calibration observations.

   On-board processing and data rate: As for POF1.

Question: The SPMD appears to rule out nodding and rastering at the same time. This needs to be clarified.

Instrument and Spacecraft Functions used and their parameters:

Table 5.6: Photometer Observatory Function POF4: Raster Mapping				
Instrument Function: Photometer Chop				
No.	**Parameter**	**Range of values**	**Nominal value**	**Comments**
1	Chop frequency	As for POF3		
2	Chop direction	As for POF3		
3	Chop throw	As for POF3		
Instrument Function: Photometer Jiggle				
4	Jiggle pattern	As for POF3		
5	Number of chop cycles/jiggle position	As for POF3		
6	Number of jiggle cycles/nod position	As for POF3		
7	Total integration time per raster point	As for POF3 except time per raster point		
Spacecraft Function: Nod				
1	Nodding	As for POF3		
2	Telescope nod period	As for POF3		
3	Nod direction	As for POF3		
4	Nod throw	As for POF3		
5	Total number of nod cycles per raster point	As for POF3 except no. of cycles per raster point		
Spacecraft 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

5.3.8 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:

POF5 is composed of the following instrument and Spacecraft Functions

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

1. The line scans are carried out along parallel lines as described in Section 2.
2. Chopping and nodding are not performed.
3. The telescope is scanned continuously across the sky. The spacecraft can scan at rates between 0.1 arcsec./sec and 1 arcmin./sec.(*SPMD*, p.8).
4. The scan direction must be in spacecraft coordinates.
5. 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. 5.8.

   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.)
6. 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.

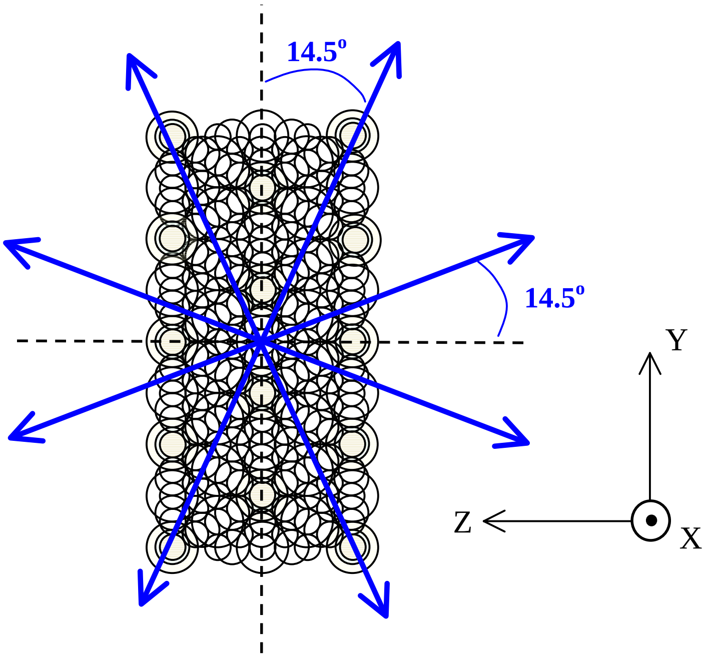


Figure 5.8: Allowed scan directions.

Detector sampling:
The demodulated detector signals are to be sampled at 25 Hz (TBC) with 16-bit resolution.
On-board processing and data rate: As for POF 1. 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 in the telemetry when the telescope has reached its steady angular velocity. Alternatively, the information needed for SPIRE to generate one should be readily obtainable in the pointing history information (e.g., record of angular velocity).

Instrument and Spacecraft Functions used and their parameters:

Table 5.7: Photometer Observatory Function POF5: Scan Map Without Chopping

Instrument Function: Photometer Non-Chop				
No.	**Parameter**	**Range of values**	**Nominal value**	**Comments**
1	Chopping	OFF	OFF	
Spacecraft Function: Normal Line Scanning				
1	Scan direction	One of the 8 directions indicated in Fig. 5.8 above.	TBD	
2	Scan rate	Min = 0.1 arcsec./sec. Max = 60"/sec.	TBD. Possibly ~ 20"/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

5.3.9 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. POF6 is composed of the following instrument and Spacecraft Functions

Instrument Function:	Photometer Chop
Spacecraft Functions:	Normal Line Scanning

2. The line scans are carried out as for POF5.
3. Nodding is not performed.
4. Chopping is performed, in the direction parallel to or perpendicular to the direction of the telescope scan. This implies a 1 Hz chopping frequency as we have to go in both axes.
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 1arcsec. on the sky (roughly 1/20th of a beam at 250 μm). The maximum allowed scan rate in arcsec./sec. is then the same as f_{chop} in Hz: e.g., for f_{chop} = 1 Hz, the maximum scan rate is 1"/sec.

Detector sampling, on-board processing and data rate: As for POF5.

Instrument and Spacecraft Functions used and their parameters:

Table 5.8: Photometer Observatory Function POF6: Scan Map With Chopping

Instrument Function: Photometer Chop				
No.	**Parameter**	**Range of values**	**Nominal value**	**Comments**
1	Chop frequency	0.2 (TBC) – 1 Hz	1 Hz	
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	
Spacecraft Function: Normal Line Scanning				
1	Scan direction	As for POF5		
2	Scan rate	As for POF5		
3	Angular length of each line scan (D_1)	As for POF5		
4	Number of lines (N)	As for POF5		
5	Angular distance between successive steps (d_2)	As for POF5		

5.3.10 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 POF3 (7-Point Jiggle Map).

Description:

1. POF6 is composed of the following instrument and Spacecraft Functions

Instrument Function:	Photometer-Chop
Spacecraft Functions:	Nod

2. SPIRE does a standard seven-point jiggle observation (POF3).
3. The offset of the source with respect to the commanded pointing is computed by the DPU using the recorded data.
4. The calculated pointing offsets ($\Delta\theta_Y$ and $\Delta\theta_Z$) are
   (a) implemented by the BSM (baseline) or
   (b) transmitted to the spacecraft AOCS.
5. If (b), the AOCS checks that the required telescope movement is within the acceptable limits and executes it.
6. (a) The AOCS transmits a message to SPIRE confirming that the pointing correction has been implemented,

   OR

   (b) 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. 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).

5.3.11 POF8: Photometer Calibrate

To be written.

Essential features:

- Calibrator will be powered by one of a pre-selected set of waveforms
- Detector signals will be recorded
- Typical duration of sequence ~ 10 sec.
- BSM must be at its rest position and the telescope pointing fixed so that the only signal modulation is from the calibrator

Open question:

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

5.4 Observatory Functions for Spectrometer

The Spectrometer Observatory Functions (SOFs) will depend on the type of source being observed; point or extended. They 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. At present there are four SOFS. It may be feasible to have only two by combining SOF1 with SOF2 and SOF3 with SOF4.

5.4.1 SOF1: Point Source Spectrum – Low or Medium Resolution

Purpose
To take a spectrum of a point source that is well centred on the central detectors of the FTS 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. Double sided interferograms are taken.

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 Spacecraft Functions:

Instrument Function:	Spectrometer Scan
Spacecraft Function:	Pointed

2. If not already powered on, the FTS calibrator is switched on to a pre-defined level and allowed to stabilise for TBD minutes.

3. The telescope is pointed at a known position, with the source lying on the central detector of the short-wavelength array - pointing offset (θ_{YS}, θ_{ZS}).

4. The FTS mirror mechanism is scanned from –0.32 cm to +0.32 cm 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 data 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 lossless 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 this mode is differentiated from the high resolution mode described below.

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

Instrument and Spacecraft Functions used and their parameters:

Table 5.9: Spectrometer Observatory Function SOF1: Low/Medium Resolution Point Source

No.	Parameter	Range of values	Nominal value	Comments
Instrument Function: Spectrometer Scan				
1	Mirror Velocity	0.02-0.1 cm s^{-1} (depends on stability of the instrument and the response of the detectors)	TBD	
2	Scan Range	Between ±0.07 cm (R=2 cm^{-1}) and ±0.35 cm (R=0.4 cm^{-1})	N/A	These scan ranges allow some extra range for mirror turn-around.
3	Total number of scans	Minimum of 3 for comparison and deglitching	> 1 min	The minimum integration time is 5 seconds for the minimum resolution. This would be inefficient given telescope motion overheads
Spacecraft Function: Pointed				
1	Pointed	(θ_{YS}, θ_{ZS})	N/A	The spacecraft is not required to do anything else

5.4.2 SOF2: Point Source Spectrum – High Resolution

Purpose

This Observatory Function is designed to take a spectrum of a point source centred on the central detectors of the arrays. The spectrum is taken wit a resolution greater than 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 of SOF2 for a resolution of 0.04 cm^{-1}. The distance the FTS mechanism has to scan will be set by the required resolution.

1-3: As for SOF 1

4. The FTS mirror mechanism is scanned from –0.32 cm to +3.2 cm 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 are compressed using lossless compression. Each raw interferogram will have a size of ~ 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. Scans are repeated until the desired integration time has been reached.

Instrument and Spacecraft Functions used and their parameters:

Table 5.10 Spectrometer Observatory Function SOF2: High Resolution Point Source				
Instrument Function: Spectrometer Scan				
No.	**Parameter**	**Range of values**	**Nominal value**	**Comments**
1	Mirror Velocity	As for SOF1		
2	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-around.
3	Total number of scans	Minimum of 3 for comparison and deglitching	None	The minimum integration time actually on source per pointing is 108 seconds for the maximum resolution
Spacecraft Function: Pointed				
1	Pointed	As for SOF1		

5.4.3 SOF3: 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 low-frequency jiggle and taking one or more interferograms 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.

1-4: As for SOF1

5. The BSM is used to make an n-point jiggle map as in POF3. The mirror is held at each position while several FTS scans are carried out.

6. For full sampling at all wavelengths, n = 25. 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 350 μm: $2\lambda/D$ = 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.

7. At each jiggle position the FTS mirror mechanism is scanned. The number of interferograms required per position is TBD (a minimum of three would seem sensible, and could be built up either by repeating the jiggle three times or doing three scans at each position of a single jiggle). With three scans per position, 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 around ten minutes.

8. 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.

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

Instrument and Spacecraft Functions used and their parameters:

Table 5.11: Spectrometer Observatory Function SOF3:
Fully Sampled Spectral Map within FOV - Low/Medium Resolution

Instrument Function: Spectrometer Scan				
No.	**Parameter**	**Range of values**	**Nominal value**	**Comments**
1	Prime detector	As for SOF1		
2	Mirror Velocity	As for SOF1		
3	Scan Range	As for SOF1		
Instrument Function: Spectrometer Jiggle				
1	Jiggle pattern	n-point with positions $(\Delta\theta_Y,\Delta\theta_Z)$ with respect to the pointed position n = 25, 64 θ = 2-9"	n = 25 $(\Delta\theta_Y,\Delta\theta_Z)$ are TBD	The number of points could just be fixed as one number
2	Number of FTS scans per 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 - it depends on the drifts and noise
3	Total number of jiggles	Min = 1 Max = TBD	None	
Spacecraft Function: Pointed				
1	Pointed	As for SOF1		

5.4.4 SOF4:

To be written. Same as SOF3 except for data configuration.

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

1. INTRODUCTION

This note summarises the assumptions we currently make about data sampling and the estimated telemetry rate requirements. It has been updated following selection of the feedhorn detectors.

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 = 21 hours

2. PHOTOMETER

2.1 Assumptions for photometer

- 280 detectors plus 20 additional channels = 300
- 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 is 24 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 14. Briefly this is arrived at as follows:

- Telescope background power on 250 μm detector (pW)	8
- Overall NEP for 250 μm detector (W $Hz^{-1/2}$)	14×10^{-17}
- Signal bandwidth of detectors (Hz)	20
- Biggest signal we'll ever digitise and telemeter (pW)	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:	

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

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 16. 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

$$\frac{(2)(12 \times 10^{-12})}{14 \times 10^{-17}\sqrt{20}} = 3.8 \times 10^4 \equiv 15.2 \text{ bits - call it 16}$$

2.4 Data rates for the photometer

2.4.1 Chopping

We assume
- Chopping at $f_c = 2$ Hz (the maximum rate)
- Effective sampling at 24 Hz for each detector (i.e., 6 samples per chop half-cycle)
- Observing efficiency = 90%
- Averaging of each half-cycle on board to produce 10 numbers per detector per second
- Data can be
  (i) transmitted to the ground at 10 numbers per detector per second without on-board subtraction (this is essential for deep survey observations to avoid increasing the confusion noise); or
  (ii) averaged on board by computing the difference between half-cycles, with these differences transmitted to the ground at a rate of 5 numbers per detector per second (this involves loss of information, but may be acceptable for non-confusion-limited observations).

The effective data rates are then :

24 samples per detector per second
x 300 channels
x 16 bits per sample
x 0.9 observing efficiency
x 21/24 fraction of 24 hrs used
= **91 kbs**

This still leaves some spare telemetry capacity (but it may be problem if the effective rate is much less than 100 kbs.

2.4.2 Scanning without chopping

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 assume that we will need to be able to cope with this scan rate.
- The FWHM beams on the sky are approximately 17, 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.
- 1/f noise is negligible so that chopping/dithering is not necessary

The detectors can be sampled at 24 Hz as for chopping mode, giving a comfortable oversampling factor with respect to the 7 Hz requirement. The net telemetry rate will thus be the same as for chopping mode: 91 kbs. The telemetry rate can be reduced if necessary with negligible consequences for the quality of the data.

2.4.3 Scanning or stepping with chopping

In this case, the assumptions are as above, except that 1/f noise dictates that chopping must be carried out at some frequency f_d. If the telescope is scanned continuously at the same time, the scanning speed must be chosen so that the data are not smeared by significant beam motion occurring during the chop cycle. A reasonable criterion may be set by stipulating that the telescope must scan by less than one tenth of a 250-μm beam (2 arcsec.) during one half-cycle of the chop. This gives

$$\text{scan rate} < 4f_d \ \text{arcsec./sec.}$$

With a maximum available dithering frequency of 5 Hz, the scan rate must be **less than 20 arcsec./sec.** The data rates in this mode are the same as for chopping, as outlined in Section 2.4.1.

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:

  19 +37 = 56 detectors + 4 extra channels = 60
  Detectors assumed to have 20 Hz 3-dB frequency and are sampled at 80 Hz.
  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 maximum instantaneous data rate before decimation = 60*16*80*0.9 = 69 kbs.

APPENDIX B: OBSERVING SEQUENCES

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

APPENDIX C: FIRST POINTING MODES (= ANNEX 1 OF THE IID-A)

Annex 1

FIRST/Planck Project

FIRST Pointing Modes

DOCUMENT CHANGE RECORD			
DATE	ISS/REV	CHAPTERS	REMARKS
September-97	1		New document
August-99	2	all	introduction of quaternions, moving patterns and generalised position switching and nodding

TABLE OF CONTENTS

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1 INTRODUCTION

FIRST/Planck is an ESA mission that combines the FIRST and the Planck missions within one single programme.

The Far Infrared and Sub-millimetre Telescope (FIRST) is dedicated to perform astronomical observations in the far-infrared and sub-millimetre wavelength range. FIRST, the fourth European Space Agency (ESA) cornerstone mission is a multi-user observatory type mission. The detectors of the FIRST instruments have to be cooled to cryogenic temperatures in the range of 0.3 to 2K in order to reach the necessary sensitivity for the observation of a variety of weak radiation sources.

Planck will image the temperature of anisotropies of the Cosmic Microwave Background (CMB) over the whole sky with a sensitivity of $\Delta T/T$ – 2 A 10^{-6} and an angular resolution of – 10 arc-minutes. This objective requires a cryogenic temperature of – 0.1K for bolometers, – 20K for HEMT (High Electron Mobility Transistors) amplifiers, and a cold low emissivity telescope. Planck is the third Medium Size mission (M3) in ESA’s long-term scientific plan Horizon 2000.

This document defines requirements for FIRST pointing modes to support Scientific Observations, in particular to make maps of extended objects, or to make high sensitivity measurements. This document is called up as an applicable document in the FIRST/Planck Satellite System Specifications PT-RS-05991.

2 RASTER POINTING

2.1 Normal raster pointing

Raster pointing is a series of fine pointing observations of equal duration (*t*), separated by slews, in order that the pointing of the telescope axis moves in a raster pattern as defined in Fig. 1. In this figure the following notations are used:

M is the number of pointings per line.

N is the number of lines.

d_1 is the angular distance between successive steps.

d_2 is the angular distance between successive lines.

In addition the inertial attitude of the pattern is defined by the quaternion Q_{rast} of the 1st raster point and an angle φ defining the rotation of the pattern axes with respect to local instrument axes.

The raster parameters, M, N, d_1 and d_2 are within the following range and resolution:

M: 2 - 32

N: 1 - 32

d_1: 2 arcsec - 4 arcmin; resolution: 0.5 arcsec

d_2: 2 arcsec - 4 arcmin or 0; resolution: 0.5 arcsec

Note that d_2 being zero, means that it shall be possible to scan N times the points of a single line.

The duration of stable pointing at any position, *t*, will be between 10 seconds and 30 minutes.

2.2 Raster pointing with OFF-position

Raster pointing with OFF-position is a special form of raster pointing where, after a specified number of raster points (ON positions), the spaceraft slews to a predefined point (the OFF position), after which it resumes its raster pointing where it left the raster before going to the OFF position. The number of raster pointings (K) before going to the OFF position is determined by the timing characteristics of the raster pointing such that the time between each subsequent OFF position is less than some characteristic stability time of the instrument. This form of raster pointing is shown in Fig. 2.

For the ON positions, the raster is defined by the parameters Q_{rast}, φ, M, N, d_1 and d_2, with for each position an equal observation time *t*. The definition of these parameters is given above for normal raster pointing and its range and resolution are specified below.

The OFF position is defined by the parameter Q_{off}, specifying the quaternions of the OFF position in inertial coordinates.

K is the number of consecutive ON positions before going to the OFF position, and t_{off} is the time of stable pointing in the OFF position.

The pattern is followed line by line and where after each K ON positions the spacecraft moves to the OFF position. After each OFF position, the raster pointing shall be resumed for the next K ON positions, etc. (Fig. 2).

The raster parameters, M, N, K, d_1 and d_2 are within the following range and resolution:

M: 2 - 32

N: 1 - 32

K: 2 - M N

d_1: 2 arcsec - 4 arcmin; resolution: 0.5 arcsec

d_2: 2 arcsec - 4 arcmin or 0; resolution: 0.5 arcsec

The maximum value of K being equal to the total number of ON positions implies normal raster pointing with only a single OFF position pointing at completion of the raster.

Like for normal raster pointing, d_2 being zero means that it shall be possible to scan N times the points of a single line.

The duration of stable pointing at any position, t, will be between 10s and 30 minutes.

The coordinates of the OFF position with respect to the centre of the map are within the following range and resolution:

d_{1off}: ±(0 arcmin - 2 degrees); resolution: 0.5 arcsec

d_{2off}: ±(0 arcmin - 2 degrees); resolution: 0.5 arcsec

The duration t_{off}, of stable pointing in the OFF position is within the range TBD s to TBD min.

3 LINE SCANNING

3.1 Normal line scanning

This is a scanning mode along short parallel lines, such that the telescope axis moves as shown in Fig. 4.3-3 with parameters as defined below:

N is the number of lines.

D_1 is the angular extent of the lines.

d_2 is the angular distance between successive lines.

The inertial attitude of the pattern is defined by the quaternions Q_{scan} of the beginning of the 1st scan line and an angle φ defining the rotation of the scan lines with respect to local instrument axes.

The pattern shall be followed line by line in the way shown by the arrows in Fig. 3.

The scan parameters, N, D_1 and d_2 are within the following range and resolution:

N: 1 - 32

D_1: 1 arcmin - 110 deg; resolution: 1 arcmin

d_2: 2 arcsec - 4 arcmin or 0; resolution: 0.5 arcsec

Note that the minimum of d_2 being zero, means that it shall be possible to scan N times the same line.

The scan rate, r, shall be changeable by ground command and will be between 0.1 arcsec/s and 1 arcmin/s with a resolution of 0.1 arcsec/s.

3.2 Line scanning with OFF-position

Line scanning with OFF-position is a special form of line scanning where, after a specified number of lines, the spacecraft slews to a predefined point (the OFF position), after which it resumes its line scanning where it left the pattern before going to the OFF position. The number of lines (K) before going to the OFF position is determined by the timing characteristics of the operation such that the time between each subsequent OFF position is less than some characteristic stability time of the instrument. This form of line scanning is shown in Fig. 4.

The line scan pattern is defined by the parameters Q_{scan} , φ, N, D_1 and d_2 as given above.

The OFF position is defined by the parameter Q_{off}, specifying the quaternions of the OFF position in inertial coordinates.

K is the number of consecutive lines before going to the OFF position, and t_{off} is the time of stable pointing in the OFF position.

The pattern shall be followed line by line in the way shown by the arrows in Fig. 4 and where after each K lines the spacecraft moves to the OFF position. After each OFF position, the line scanning shall be resumed for the next K lines, etc.

The scan parameters, N, D_1 and d_2 are command within the following range and resolution:

N: 1 - 32

K: 1 - N

D_1: 1 arcmin - 2 deg; resolution: 1 arcmin

d_2: 2 arcsec - 4 arcmin or 0; resolution: 0.5 arcsec

The maximum value of K being equal to the total number of lines implies normal line scanning with only a single OFF position pointing at completion of the line pattern.

The scan rate, r, is between 0.1 arcsec/s and 1 arcmin/s with a resolution of 0.1 arcsec/s.

The coordinates of the OFF position with respect to the centre of the map shall be changeable by ground command within the following range and resolution:

d_{1off}: ±(0 arcmin - 2 degree); resolution: 0.5 arcsec

d_{2off}: ±(0 arcmin - 2 degree); resolution: 0.5 arcsec

The duration t_{off}, of stable pointing in the OFF position is within the range TBD s to TBD min.

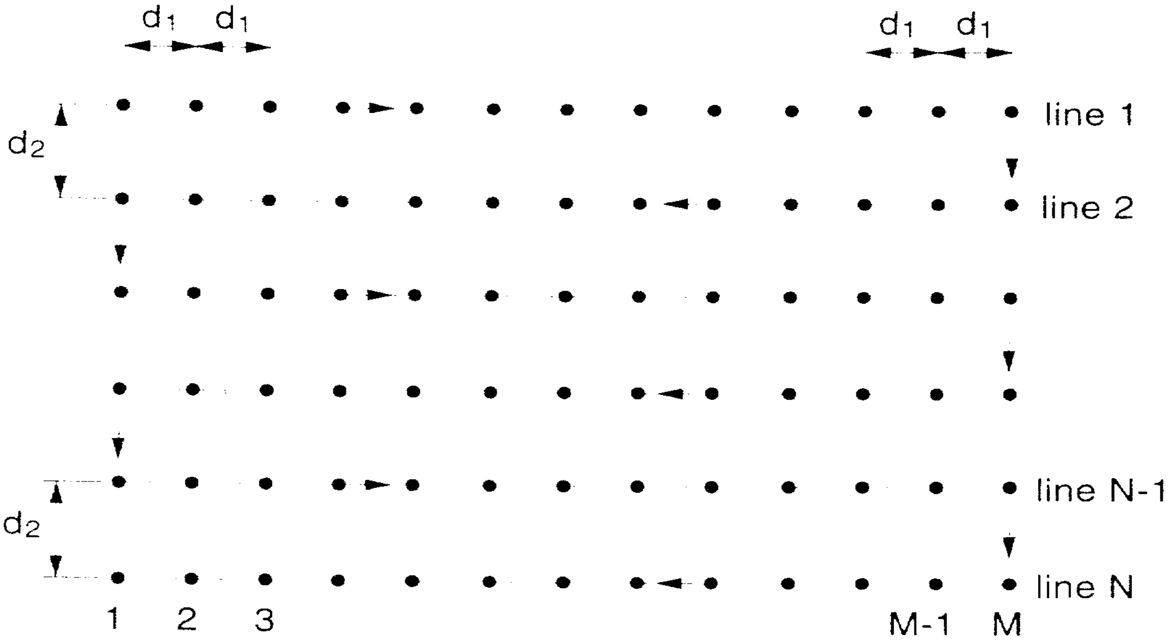

FIGURE 4.3-1 NORMAL RASTER POINTING

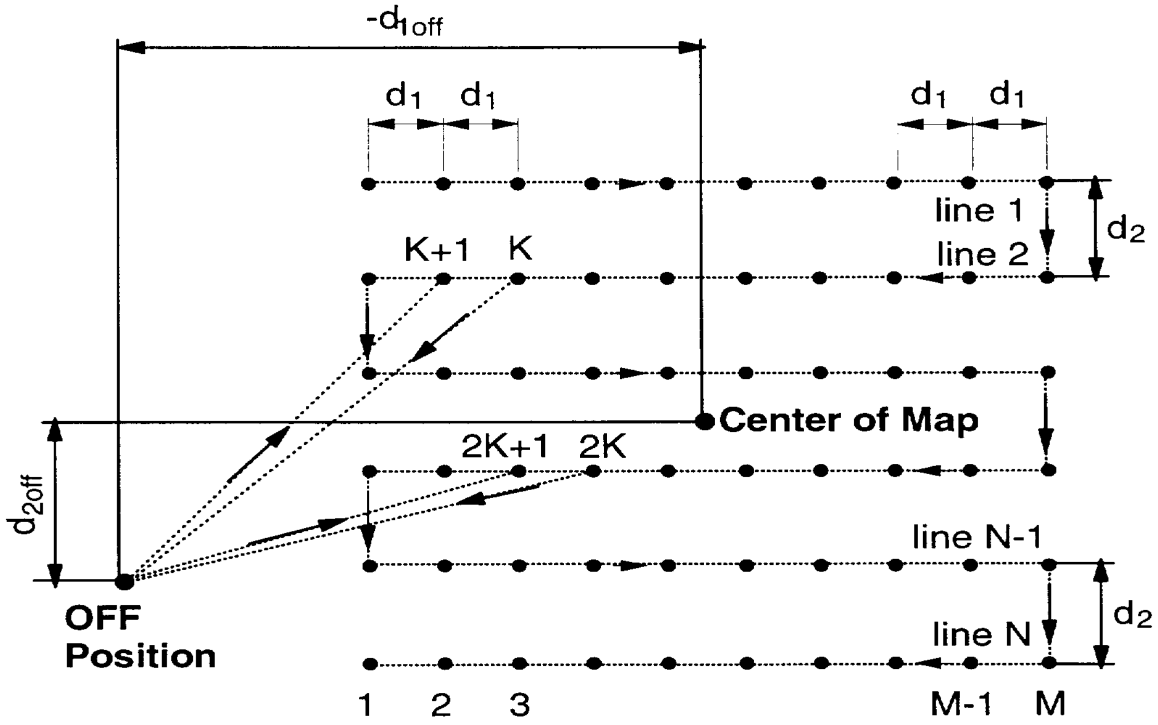

FIGURE 4.3-2 RASTER POINTING WITH OFF-POSITION

4 TRACKING OF SOLAR SYSTEM OBJECTS

The satellite will be able to follow, by ground command of a series of fine pointings, objects such as planets, comets, etc. having a maximum speed relative to the tracking star of 10 arcsec/min.

The trajectory of such solar system object will be described by chebyshev polynomials (TBC).

The inertial attitue defining the raster (Q_{rast}) and line scan patterns (Q_{scan}) may also be referenced to a solar system object.

5 POSITION SWITCHING

Position switching is an observing mode in which the instrument line of sight is periodically changed between a target source and a position off the source.

Periodically the telescope pointing direction is changed between a target source and some position off the source.

This is a special case of normal raster pointing with the following raster parameters:

M: 2

N: 1 - n

d_1: 2 arcsec – 2 deg; resolution: 0.5 arcsec

d_2: 0

The integration times in the "on" and "off" positions are equal and are within the range of 10 s (TBC) to 20 min (depending on the throw).

6 NODDING

Nodding is an observing mode in which the target source is moved from one instrument chop position to the other chop position. In this case the pointing direction will change in the direction of the instrument chopper throw.

Periodically the telescope pointing direction is changed such that the source is moved from one instrument chop position to the other position.

This is a special case of normal raster pointing with the following raster parameters:

φ: 0

M: 2

N: 1 - n

d_1: 2 arcsec – 16 arcmin; resolution: 0.5 arcsec

d_2: 0

The integration times in both positions are equal and are within the range of 10 s (TBC) to 20 min (depending on the throw).

7 FIRST Peaking Up

During the observation of bright sources, a way of correcting the blind pointing error when the source is bright enough is envisaged. The spacecraft perform a five-point cross scan (left, right, centre up, down) and a double gaussian is fitted to the two three point linear scans by the instruments.

The pointing offsets in the two orthogonal directions are computed by the instrument and the spacecraft pointing is adjusted accordingly before a much longer integration on the now correct position is carried out.

Bi-directional exchange of position pointing between spacecraft and instrument is required.

On acquiring a source the spacecraft shall carry out the five point routine as a standard sequence (with an integration time per point pre-selected to match the expected source brightness).