Herschel SPIRE

Detector Subsystem
Specification Document

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Draft 2	Made into spec for all units of detector subsystem and compatible with IRD	4 July 2000	Second Draft
Draft 3	Combine comments from Bruce and Jamie, redefine terminology.	10 July 2000	Third draft
Draft 4	Further finessing.	17 July 2000	Fourth Draft
Draft 5	Include CRR RFA.	2 August 2000	Fifth Draft
Draft 6	Change wording in section 3.1.	3 August 2000	Sixth Draft
Draft 7	Changes to DRCU specifications in response to detector meeting.	1 March 2001	Seventh Draft
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Section	**Reason For Change**
3.1.1	Detailed changes to detector specifications. Inclusion of table of detector design parameters.
3.3.2	Numerous additional specifications requiring agreement from RAL/QMW. Section also includes explicit numbers of required channels, signal flow diagram, design values for detectors, and noise budget.
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Section	**Reason For Change**
2.4 Rec/Dels	Includes an explicit section on receivables and deliverables

1 Introduction

1.1 Purpose of the document

This specification defines the requirements applied to the performance, design, qualification, and interfaces of the SPIRE detector subsystem. It is applicable to the STM, the CQM, the PFM and the FS as described in this document.

1.2 Acronyms and Abbreviations

1.2.1 Acronyms

AD	Architectural Design
ATP	Acceptance Test Plan
AVM	Avionic Model
BDA	Bolometric Detector Array
CPP	Common parts Procurement
CQM	Cryogenic Qualification Model
DCU	Detector Control Unit
DDD	Detailed Design Document
DQE	Detective Quantum Efficiency
DRCU	Detector Control and Readout Unit
EMC	ElectroMagnetic Compatibility
EMI	ElectroMagnetic Interference
ESA	European Space Agency
FIRST	Far InfraRed and Submillimeter Telescope
FPS	Focal Plane Structure (mechanical housing)
FPU	Focal Plane Unit
FS	Flight Spare
IBDR	Instrument Baseline Design Review
ICD	Interface Control Document
ICDR	Instrument Critical Design Review
IRD	Instrument Requirements Document
ISVR	Instrument Science Verification Review
JFET	Junction Field Effect Transistor
JPL	Jet Propulsion Laboratory
NA	Not Applicable
NEP	Noise Equivalent Power
LIA	Lock-In Amplifier
PA	Product Assurance
PFM	Proto Flight Model
SPIRE	Spectral and Photometric Imaging REceiver
STM	Structural Thermal Model
TBC	To Be Confirmed
TBD	To Be Defined
TBW	To Be Written

1.3 References

1.3.1 Applicable Documents

Document Reference	Name	Number/version/date
AD1	SPIRE Instrument Requirements Document	SPIRE-RAL-PRJ-000034 Draft .31 25 May 2000
AD2	FIRST/Planck Instrument Interface Document Part A	SPIRE-ESA-DOC-000178 Rev 0-3 15 May 2000
AD3	FIRST/Planck Instrument Interface Document Part B Instrument "SPIRE"	SPIRE-ESA-DOC-000275 Rev 0-4 15 May 2000

1.3.2 Reference Documents

Document Reference	Name	Number/version
RD1	SPIRE A Bolometer Instrument for FIRST (The SPIRE proposal to ESA) *The SPIRE Consortium*	SPIRE-RAL-PRJ-000020
RD2	Intstrument Sensitivity Models	TBD

1.4 Overview of the document

TBW

2 Subsystem Description

The SPIRE instrument is designed to observe astronomical sources in the 200 to 700 μm waveband. To accomplish this it will use bolometric detector arrays based on silicon nitride "spider web" absorbers with NTD germanium thermistors. The detectors will have feedhorn focal plane optics to efficiently couple the radiation from the SPIRE optics onto the bolometers.

The detector sub-system consists of five Bolometric Detector Arrays (BDA) – three for the SPIRE photometer channel:

PLW – Long wavelength photometer array
PMW – Medium wavelength photometer array
PSW – Short wavelength photometer array

And two for the SPIRE spectrometer channel:

SLW – Long wavelength spectrometer array
SSW – Short wavelength spectrometer array

These arrays are cooled to an operating temperature of close to 300 mK by means of thermal straps to a ^{3}He sorption cooler. Electrical cables connect the BDAs to the JFET readout modules. As the JFET box is located outside of the 4 K structure, the cables must be routed through the 2 K and 4 K structure and out to the JFET modules. A mechanical interface defines the mounting of JFET modules into the JFET housing. The electrical outputs from the JFET modules connect to a wiring harness that leads from the optical bench to hermetic connectors at the wall of the Herschel cryostat, and then to the SPIRE warm electronics units. Electrical signals from the JFETs are amplified and conditioned by the Detector Control Unit (DCU), which is a sub-unit of the Detector Readout and Control Unit (DRCU). A block diagram of the SPIRE detector sub-system is shown in figure 2.1 and indicates those units which are the subject of this specification document. A block diagram of the SPIRE instrument is shown in figure 2.2 to indicate the relationship between the detector subsystem and the other sub-systems within the instrument.

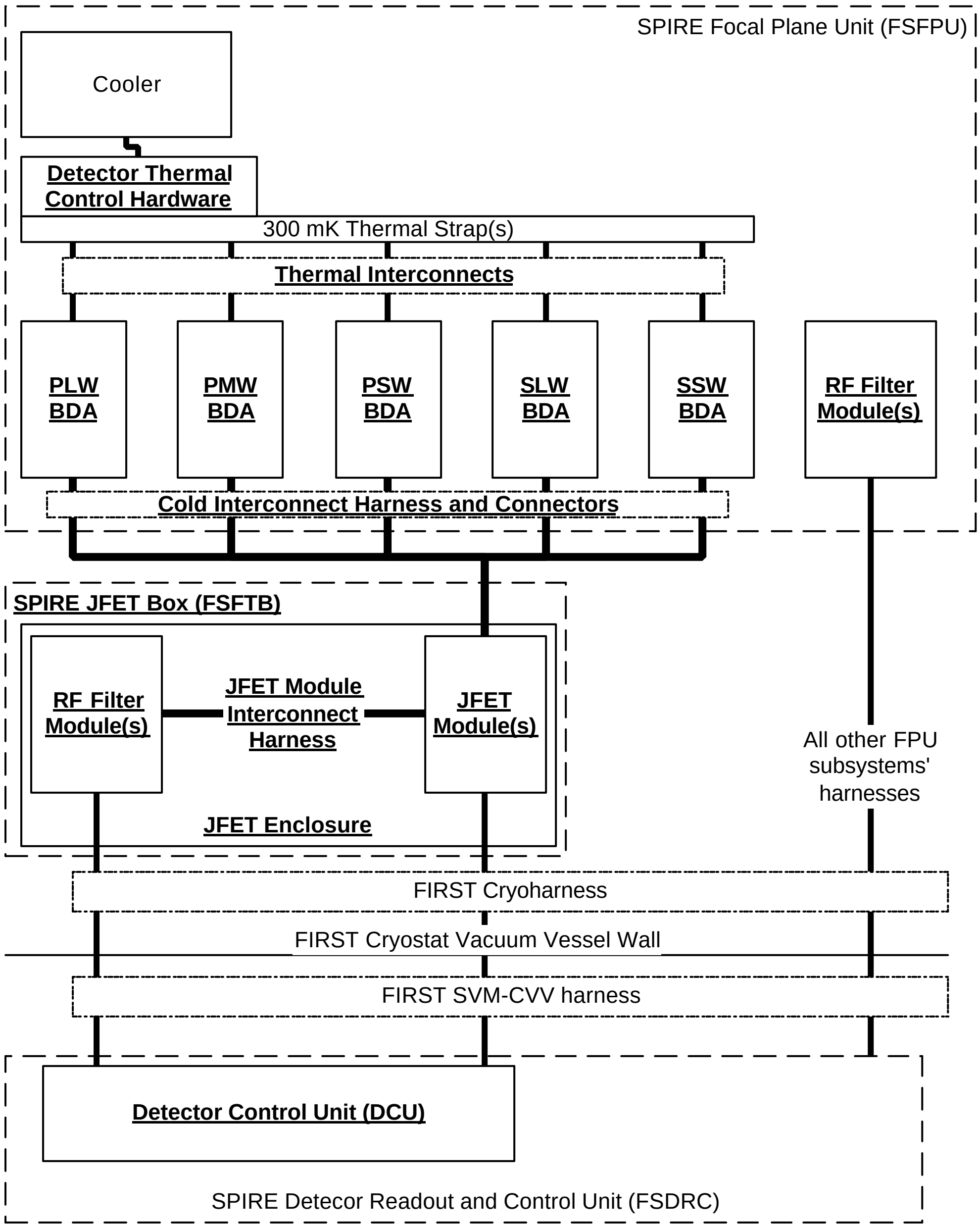


Figure 2-1: Block diagram of the SPIRE detector sub-system. The units that are indicated in underlined bold text belong to the detector subsystem and are the subject of the present specification document.

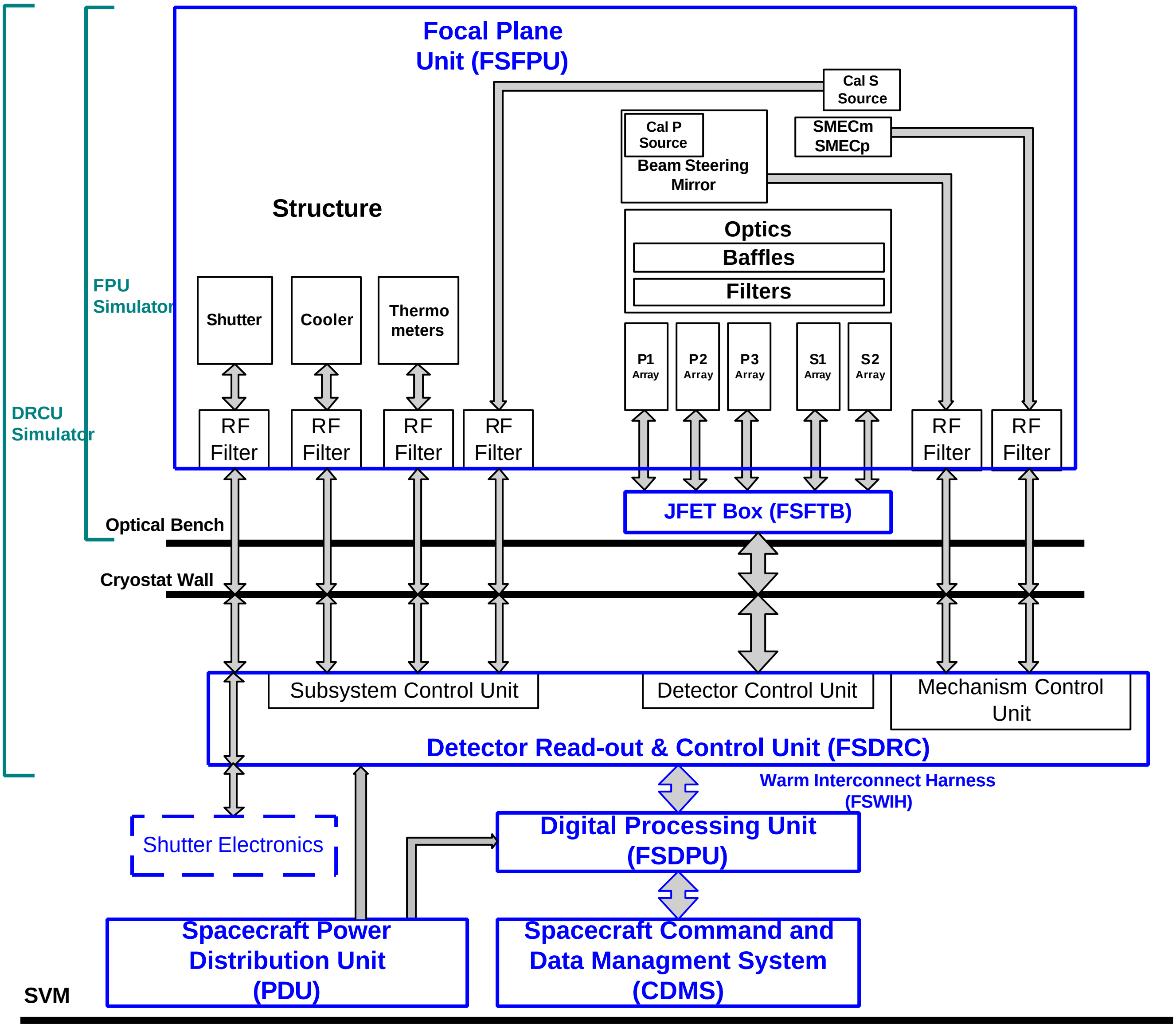


Figure 2-2: SPIRE instrument sub-system block diagram

2.1 Design

2.1.1 Bolometer Detector Array

The BDA is designed to accommodate a focal plane array of bolometric detectors operating at a temperature of close to 300 mK. The detectors couple to the cold optics of the SPIRE instrument via an array of collimating feedhorns mounted adjacent to the detector array. The feedhorns collimate sub-millimeter radiation onto the detectors, and define the detector field of view. A band-defining sub-millimeter filter is located over the feedhorn apertures at 300 mK. The focal plane array is mechanically supported and thermally isolated from the 2 K environment by a low-conductivity kevlar suspension system. The kevlar suspension must meet the tight thermal and mechanical requirements of the SPIRE instrument. The focal plane arrays are cooled to close to 300 mK by means of thermal straps to the ^{3}He sorption cooler which attach to the BDA at a defined location. A flange at 2 K provides the mechanical interface for the BDA to mount onto the 2 K structure.

The bolometric detectors are addressed by cryogenic readout cables, routed from the 300 mK focal plane array to the bottom 2 K surface. The 2 K surface serves to enclose the back end of the focal plane array from straylight. Connectors will be located at the 2 K surface to allow for ready integration into the instrument.

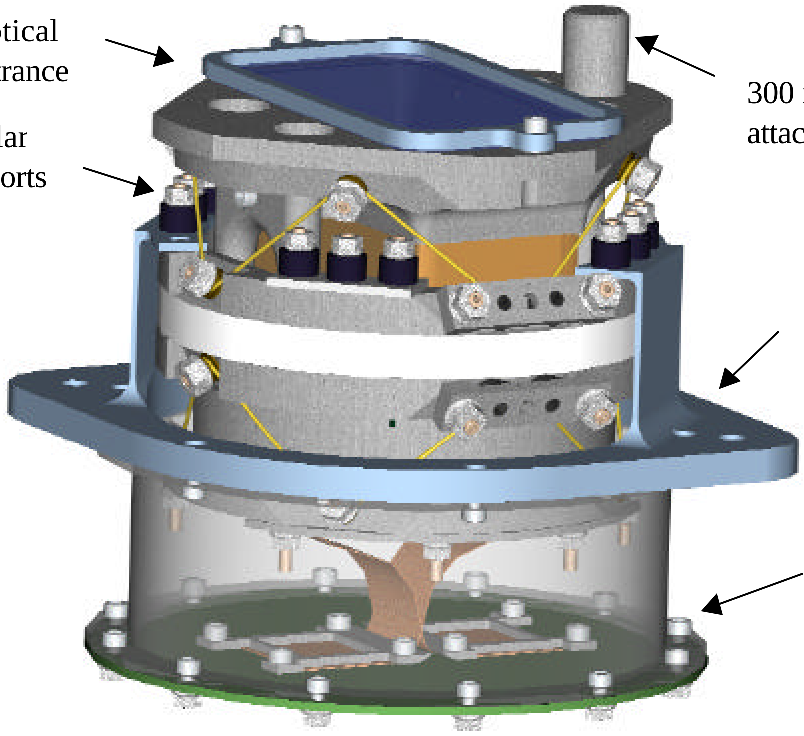


Figure 2-3: Schematic BDA Mechanical Design

2.1.2 JFET Amplifier Modules

The detector signals are power amplified by cryogenic JFET modules located at the Herschel cryostat level 2 temperature – nominally between 9 and 15 K. These modules house 24 dual JFETs that meet the tight thermal dissipation and noise specifications of the SPIRE instrument. The JFET modules are mounted into a housing at a mechanical interface defined by a mounting flange and connector interface. The JFET module is designed to attenuate thermal radiation from the 120 K JFETs by means of a light wall. Passive RF filter components located on circuit boards inside the module housing provide RF attenuation coming from the output cables. Output connectors interface to the cryogenic wiring harness going to the CVV connectors and then the warm electronics.

2.1.3 RF Filter Modules

In addition to the JFET modules there will also need to be passive RF filter modules present on all power; bias and heater lines entering the JFET Box. These will be housed in modules similar in design to the JFET modules but with only passive components. All subsystem wiring entering the FPU enclosure will also require RF filtering (see figure 2-2). These modules will be identical to those used in the JFET box and will be provided as part of the Detector Subsystem.

2.1.4 JFET Box Mechanical Enclosure

The JFET modules and RF filter modules will be mounted on the Herschel optical bench in a mechanical enclosure close to the SPIRE FPU structure. This enclosure will interface to directly to the Herschel cryostat level 2 temperature stage – at about 10 K – and will also provide a mechanical interface between the SPIRE FPU structure and the JFET modules through which the cold interconnect harness can be supported.

2.1.5 JFET Box Interconnect Harness

Any connections between the RF filter modules and the JFET modules in the JFET box will be made by use of a dedicated internal harness. This harness will be iso-thermal and can therefore be implemented in standard copper wire technology.

2.1.6 Cold Interconnect harness and connectors

The wiring diagram for a BDA is described in Fig. 2-6. Readout wires for each detector are fanned out at the focal plane array and wire bonded to a load resistor module located inside the BDA at 300 mK. The signal lines then connect to lithographed kapton cables which wirebond to an alumina fanout located at the 2 K surface at the bottom of the BDA. Connectors located at the 2 K surface allow for ready mounting and demounting of the BDA. Low-conductivity cables connect the outputs of the BDA to the JFET modules, and run from the 2 K structure to the 4 K structure to the JFET modules. Intervening connectors may be required (TBD) to allow for integration of the cables into the instrument. The outputs of the JFET modules pass through RF filters and connect to the wiring harness. Detector bias, JFET power, and JFET heater power pass through 2 separate, redundant RF filters and connect on a backplane connector into each JFET module. Separating these lines simplifies the wiring harness and reduces electrical cross talk.

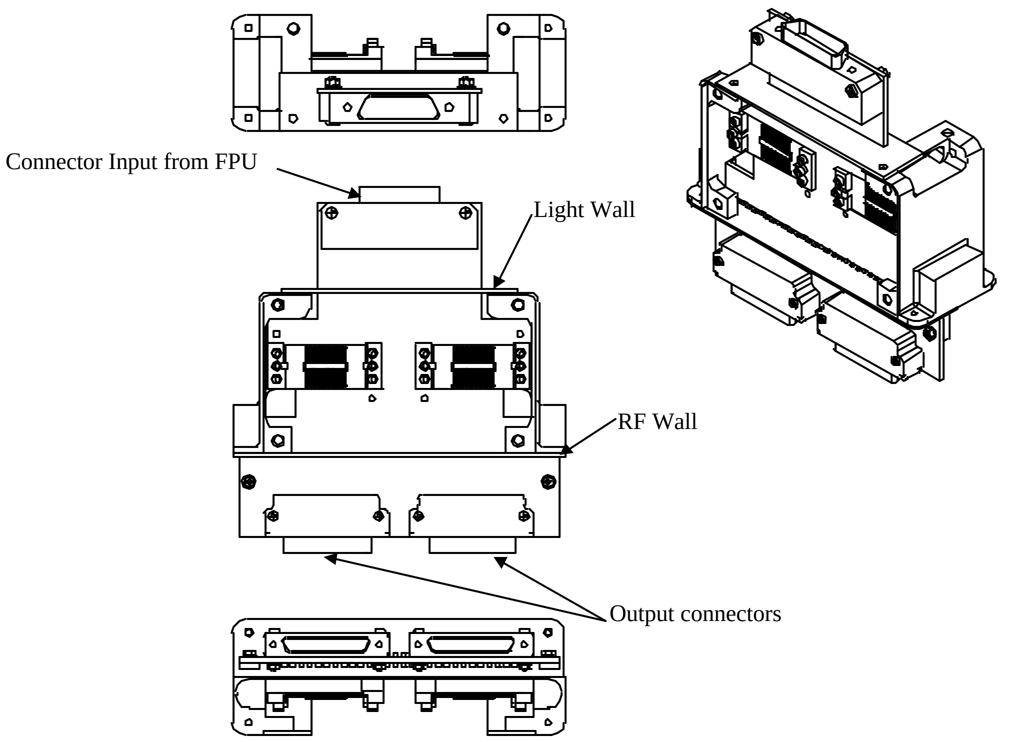


Figure 2-4: Schematic mechanical design of 2 JFET modules.

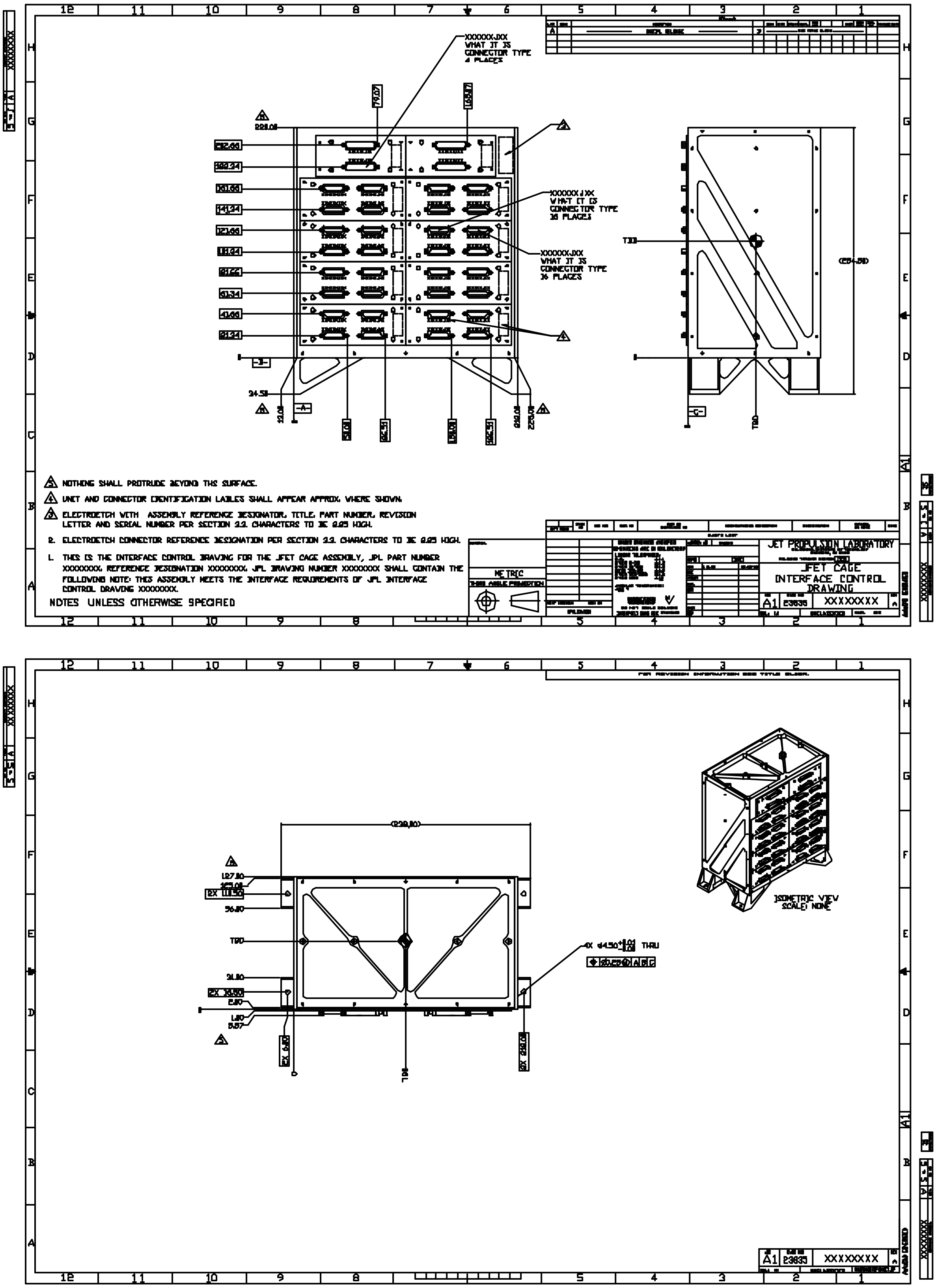


Figure 2-5: Schematic layout of the JFET box mechanical enclosure.

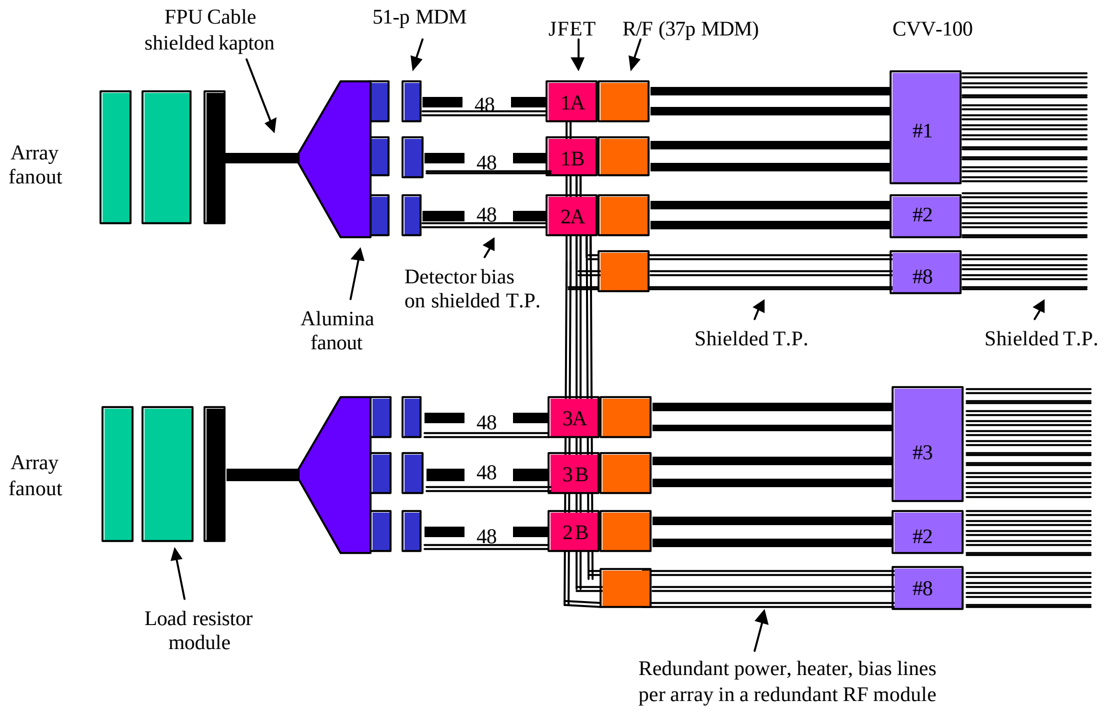


Figure 2-6: Wiring diagram for P/LW array.

2.1.7 Detector readout

The BDA arrays are readout using an AC bias and demodulation supplied by the warm DRCU (see Fig. 2-4). The AC bias modulates the signal at 100 – 300 Hz, above the 1/f knee of the JFET amplifiers and readout electronics. This relaxes the noise requirements on the JFETs, which could not be met at the audio frequencies of the detectors at the power dissipations allowed. Each BDA receives an independent bias. The warm electronics also supply power and heater lines for the JFET modules. Because the bias and JFET power lines represent single-point failures for many detectors, they are designed to be redundant.

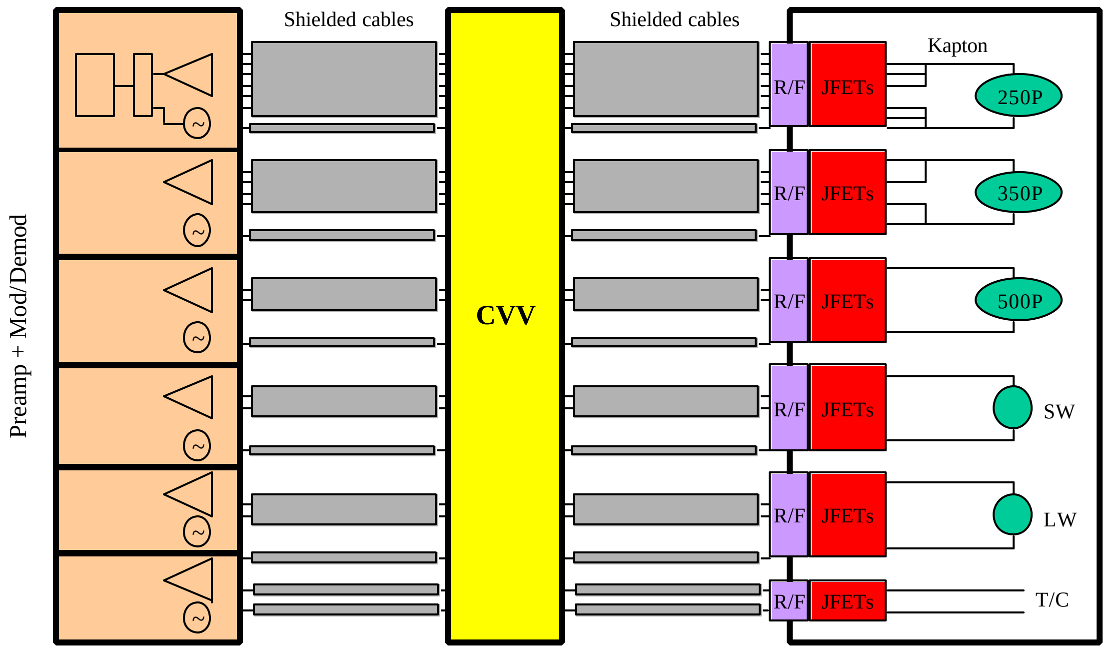


Figure 2-7: Schematic of readout of BDAs.

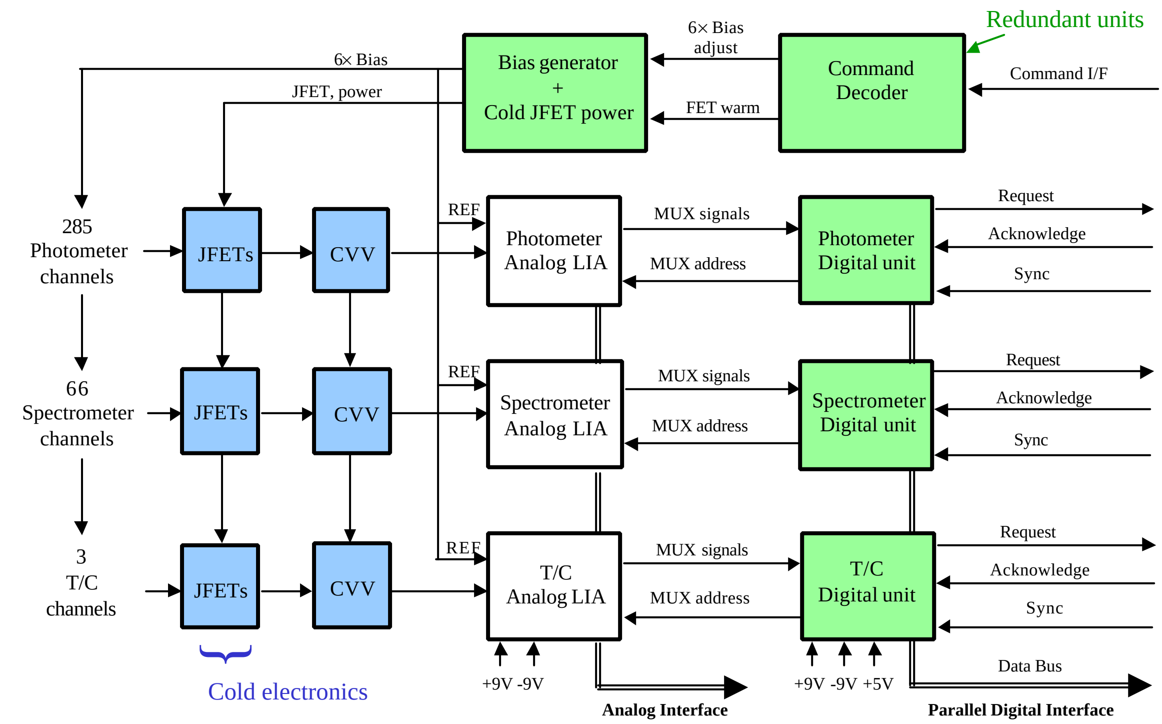


Figure 2-8: Interface between DRCU, BDA, and JFET modules.

2.1.8 Thermal Interconnects

The BDAs are mounted on the 2-K instrument structure up to 50 cm from the cold tip of the ^{3}He cooler. This necessitates the use of thermal straps between the cooler and the BDAs. These are considered part of the SPIRE structure for the purposes of subsystem definition. However, there does need to be a connection made between the thermal straps and the BDAs. The hardware associated with this connection (e.g. a copper wire) is part of the detector sub-system.

2.1.9 Thermal Control Hardware

If the ^{3}He cooler can meet the requirements placed on it in this document, there should be no need to have active control of the detector temperature. However, if, following the development phase of the instrument, there is a requirement for active control of the detector temperature, then the cold hardware for this will be provided as part of the detector sub-system. The cold hardware will consist of NTD germanium thermistors in a bridge arrangement and resistive heaters.

2.1.10 Cold Detector Simulator

The cryoharness to be provided by ESA for the Herschel cryostat, and the one to be provided for the AIV cryostat, will need to be tested to ensure that it is compatible with the requirements of the detector subsystem. To allow this a cold detector simulator will be built that will have the same electrical (noise; impedance etc) characteristics as the detector sub-systems as seen by the cryoharness. This will most likely consist of resistors in one or more JFET module housing(s) that will have the same noise and impedance characteristics when cold and the same interface to the cryoharness. The Structural Thermal Model of the JFET modules may be used for this unit.

2.2 Mission Profile

The proto-flight model of the detector sub-system units will be designed to be used for 3 (TBC) years use on the ground, 2 (TBC) years of storage and 4.25 (TBC) years in orbit.

2.3 Product Tree

The instrument models define the functionality of the hardware delivered by JPL. The STM model of the instrument will be used to characterise the thermal and mechanical performance, and to verify the electrical properties of the cold harnesses. The hardware required must therefore be thermally and mechanically representative. In addition, a full electrical harness is required, and the BDAs and JFETs must provide electrical equivalents for verification of the cryo-harnesses. JPL will supply one suspended BDA for testing in the STM FPU.

The CQM instrument is used to verify the optical and electrical performance of the instrument, and to determine potential problems with interference of various sub-systems. One operational photometer BDA with associated JFETs is deemed sufficient to characterise operation of the photometer, and two spectrometer BDAs with associated JFETs are deemed sufficient to characterise operation of the spectrometer. Temperature control will not be implemented in the CQM instrument, although data collected may indicate the need to implement temperature control in the PFM and FS instruments.

The PFM and FS instruments are to be fully operational. The FS instrument will incorporate CQM hardware delivered by JPL as defined in section 2.4 below.

2.4 Receivables and Deliverables

Table 2-4-1 indicates hardware deliverables and receivables for the SPIRE instrument. Table 2-4-2 indicates hardware required for testing the cabling for compatibility with the BDAs. All hardware required for cable testing is listed, although some items are not delivered or received by JPL. Table 2-4-2 also lists hardware exchange required by the JPL and CU test programs. Table 2-4-3 indicates documentation exchange required for defining interfaces. Receivables and deliverables for the warm electronics development with CEA/SAp are documented in a separate business agreement for the warm electronics.

Table 2-2-1a. Hardware deliverables required for STM instrument

Item	Del. by	Rec. by
P/LW EM BDA[1]	JPL	RAL
P/MW STM BDA[2]	JPL	RAL
P/SW STM BDA[2]	JPL	RAL
S/SW STM BDA[2]	JPL	RAL
S/LW STM BDA[2]	JPL	RAL
15 JFET STM modules[3]	JPL	RAL
5 (TBC) RF modules for FPU[4]	JPL	RAL
3 RF modules for JFET rack[4]	JPL	RAL
15 Harness between JFET modules and BDAs[5]	JPL	RAL
Back harnesses for JFET racks[5]	JPL	RAL

1. EM BDA is form and fit compliant, including connectors but without savers. The EM BDA has a kevlar-suspended detector section with no active detection elements. Unit will *not* have resistors for harness checkout.
2. STM BDA is form and fit compliant, including connectors but without savers. Resistors at 1.7 K allow checkout of harness. A weak thermal link will connect to 0.3 K to simulate BDA parasitic dissipation.

3. JFET STM modules are fit and form compliant, including connectors but without savers. Includes representative electrical connections and thermal dissipation. Units will be re-used in CQM instrument.
4. RF modules are fully functional and will be re-used for the CQM and FS instruments.
5. Harnesses to be re-used for the CQM and FS instruments.

Table 2-2-1b. Hardware deliverables required for CQM instrument

Item	Del. by	Rec. by
P/LW CQM BDA[6]	JPL	RAL
P/MW CQM BDA[7]	JPL	RAL
P/SW CQM BDA[7]	JPL	RAL
S/LW CQM BDA[6]	JPL	RAL
S/SW CQM BDA[6] (initial delivery)	JPL	RAL
S/SW CQM BDA[8]	JPL	RAL
2 JFET modules[9]	JPL	RAL
1 JFET/RF module[10]	JPL	RAL
P/LW BDA far-infrared filter	QMW	JPL
S/LW BDA far-infrared filter	QMW	JPL
S/SW BDA far-infrared filter	QMW	JPL

6. BDA is fully functional, but without connector savers. If the CQM BDAs provide reasonable functional equivalents, within a factor of 2 of the design NEP and time constant at optimal bias, to the flight units, the minimum performance values listed in section 3 do not have to be met. It is anticipated the speed of the detectors will increase by a factor of two under non-optimal bias. The array will be re-used for the FS instrument.
7. BDA is form and fit compliant, including connectors but without savers. The array will have a kevlar-suspended detector section with no active detection elements. Unit will *not* have resistors for harness checkout. These units to be returned to JPL for refurbishment for FS deliverables.
8. BDA is fully functional, but without connector savers. This unit is delivered without environmental or performance testing. The array will be returned to JPL in time for testing for the PFM instrument.
9. JFET modules are fully functional. If the CQM JFET modules provide reasonable functional equivalents to the flight units, in the judgement of the SPIRE instrument team, the minimum performance values listed in section 3 do not have to be met. Modules to be re-used for FS instrument.
10. JFET/RF module is fully functional. Module to be re-used for FS instrument.

Table 2-2-1c. Hardware deliverables required for PFM instrument

Item	Del. by	Rec. by
P/LW PFM BDA	JPL	RAL
P/MW PFM BDA	JPL	RAL
P/SW PFM BDA	JPL	RAL
S/LW PFM BDA	JPL	RAL
S/SW PFM BDA	JPL	RAL
7 JFET modules	JPL	RAL
1 JFET/RF module	JPL	RAL
5 (TBC) RF modules for FPU	JPL	RAL
3 RF modules for JFET rack	JPL	RAL
15 Harness between JFET modules and BDAs	JPL	RAL
Back harnesses for JFET racks	JPL	RAL
T/C thermometers, heaters, fixtures, and cable (TBC)	JPL	RAL
P/LW BDA far-infrared filter	QMW	JPL
P/MW BDA far-infrared filter	QMW	JPL
P/SW BDA far-infrared filter	QMW	JPL
S/LW BDA far-infrared filter	QMW	JPL

S/SW BDA far-infrared filter	QMW	JPL

Table 2-2-1d. Hardware deliverables required for FS instrument

Item	**Del. by**	**Rec. by**
P/MW FS BDA	JPL	RAL
P/SW FS BDA	JPL	RAL
S/SW FS BDA	JPL	RAL
5 JFET modules	JPL	RAL
T/C thermometers, heaters, fixtures, and cable (TBC)	JPL	RAL
P/MW BDA far-infrared filter	QMW	JPL
P/SW BDA far-infrared filter	QMW	JPL
S/SW BDA far-infrared filter	QMW	JPL

Table 2-2-2a. Test equipment required for testing at RAL

Item	**Del. by**	**Rec. by**
JFET STM modules (listed in table 2-2-1a)	JPL	RAL
24-channel JFET cross-talk card	JPL	RAL
24-channel JFET termination card	JPL	RAL
24-channel bolometer cross-talk card	JPL	RAL
24-channel warm bolometer simulator card	JPL	RAL
STM BDAs (listed in table 2-2-1a)	JPL	RAL
24-channel DC amplifier card	JPL	RAL
AC/DC bias generator	RAL	RAL
JFET power supply	RAL	RAL
Data acquisition system for DC testing	RAL	RAL
EM DRCU electronics	CEA	RAL
RF characterisation equipment	RAL	RAL

Table 2-2-2b. Equipment required for testing at JPL and CU

Item	**Del. by**	**Rec. by**
Filter specifications for JPL test dewar	JPL	QMW
Filters for JPL test dewar	QMW	JPL
Filter specifications for CU feedhorn testing	CU	QMW
Filters for CU feedhorn testing	QMW	CU

Table 2-2-3. Documentation

Item	**Del. by**	**Rec. by**
ICD: EM BDA	JPL	RAL
ICD: STM BDA, with pinout	JPL	RAL
ICD: CQM, PFM and FS BDAs, with pinout	JPL	RAL
ICD: BDA far-infrared filter	JPL	QMW
ICD: STM JFET module, with pinout	JPL	RAL
ICD: CQM, PFM and FS JFET module, with pinout	JPL	RAL
ICD: RF filters for FPU, with pinout	JPL	RAL
ICD: RF filters for JFET rack, with pinout	JPL	RAL
ICD: T/C hardware	JPL	RAL
ICD: JFET rack	MSSL	JPL

ICD: cable length and routing	MSSL	JPL
ICD: cryoharness definition	RAL	JPL
ICD: grounding network	RAL	JPL
PA plan	JPL	RAL
AIDS for all hardware	JPL	RAL
End-item acceptance package for all hardware	JPL	RAL

3 Specification

3.1 Functional

The functional requirements on the arrays are divided into three categories, minimum performance, achieved performance to date, and design value.

Minimum performance values are quoted for information, and are based on achieved or design values with margin. Performance levels that have been achieved to date are also indicated for information. The design values approach, and are generally compliant with, the performance levels defined in the Instrument Requirements Document. For this issue of the specification document there is insufficient data on whether the design values will be met in the course of the flight model build programme. A margin will be held on all mass, thermal and power budgets at the level of the instrument as a system. If any of the required performances are not met by the flight model units the consequences will be evaluated against the impact on the performance of the instrument as a whole and extra resources allocated or the instrument specification adjusted to reflect the new situation.

3.1.1 Performance Specification

Specification ID	Description	Requirement Reference	Minimum Performance	Achieved to Date	Design Value
BDA-PER-01	BDA detector yield.	IRD-DETP-R04 IRD-DETS-R04	0.75	0.9	0.9
BDA-PER-02	The ratio of photon NEP due to radiation absorbed at the detector and total NEP, given as (NEPphoton/NEPtotal)^2 NEP includes all sources of noise at 1 Hz, measured at 300 mK, assuming a total readout noise of 10 nV/rtHz and an operating impedance of 5 MOhm.	IRD-DETP-R01	0.55 (P/LW) 0.61 (P/MW) 0.66 (P/SW) 0.61 (S/LW) 0.66 (S/SW)	- 0.70 (P/MW) - - - (10 nV/rtHz amplifier noise).	0.66 (P/LW) 0.73 (P/MW) 0.79 (P/SW) 0.73 (S/LW) 0.79 (S/SW)
BDA-PER-03	The optical efficiency of the FPU horn and bolometer assembly for the photometer arrays over the optical passband.	IRD-DETP-R01	0.45	0.45 – 0.65	0.85
BDA-PER-04	The optical efficiency of the short wavelength spectrometer horn arrays and bolometer assembly over the optical	IRD-DETS-R01 IRD-DETS-R08	0.45 (TBC)	-	0.85

	passband.				
BDA-PER-05	The optical efficiency of the long wavelength spectrometer horn arrays and bolometer assembly over 300-400 µm.	IRD-DETS-R01 IRD-DETS-R08	-	-	0.85
BDA-PER-06	The photometer detector time constant, assuming a maximum modulation frequency of 2 Hz.	IRD-DETP-R02	32 ms	14 ms (C = 1pJ/K)	14 ms (P/LW) 11 ms (P/MW) 9 ms (P/SW)
BDA-PER-07	The spectrometer detector time constant, assuming a maximum modulation frequency of 20 Hz.	IRD-DETS-R02	14 ms (S/LW) 8 ms (S/SW)	3.4 ms 4.9 ms (C = 1 pJ/K)	3.4 ms (S/LW) 4.9 ms (S/SW)
BDA-PER-08	The uniformity of the calibrated responsivity.	IRD-DETP-R03 IRD-DETS-R03	0.99	0.99	0.99
BDA-PER-09	Detector cross-talk.	IRD-DETP-R05 IRD-DETP-R06 IRD-DETS-R05 IRD-DETS-R06	-	< 5 % n-n	1 % nearest neighbors 0.1% non-nearest neighbors
BDA-PER-10	The 1/f knee frequency (total noise is sqrt(2) larger than white level).		0.1	0.03	0.03
BDA-PER-11	The performance of the bolometers assumes a nominal optical loading absorbed by bolometer (pW).	JPL			3.0 (P/LW) 4.0 (P/MW) 5.0 (P/SW) 12.5 (S/LW) 9.0 (S/SW)
BDA-PER-12	The performance of the bolometers assumes a nominal photon NEP, referred to power absorbed at the detector (e-17 W/√Hz).	JPL			4.9 (P/LW) 6.7 (P/MW) 8.9 (P/SW) 11.9 (S/LW) 12.0 (S/SW)
BDA-PER-13	The optical loading and photon NEP assumes a nominal optical efficiency of the bolometer and feedhorn.	JPL			0.85 (P/LW) 0.85 (P/MW) 0.85 (P/SW) TBD (S/LW) TBD (S/SW)

Specification ID	Description	Requirement Reference	Minimum Performance	Achieved To Date	Design Value
JFET-PER-01	Median noise of JFET module over 100 – 300 Hz.	IRD-FTB-R01	8.5	7.0	7.0

Table 3-1-1 Summary of Detector Design Values

Quantity	Units	P/LW	P/MW	P/SW	S/LW	S/SW
Q	pW	3	4	5	12.5	9
NEP_{blip}	e-17 W/√Hz	4.9	6.7	8.9	11.9	12.0
NEP_{tot}	e-17 W/√Hz	6.0	7.9	10.0	14.0	13.4
τ	ms	14.2	11.1	8.9	3.4	4.9
G_0	pW/K	50	64	80	140	210
V_{bol}	mV_{rms}	3.7	4.2	4.7	7.6	6.3
S_{dc}	e8 V/W	4.3	3.7	3.3	2.1	2.1

Table 3-1-2 Summary of Common Detector Design Values

Quantity	Value	Units
R_0	180	Ω
Δ	41.8	K
T_{bol}	0.39	K
R_{bol}	5.8	MΩ
Z/R	0.4	

3.1.2 Functional specification

Specification ID	Description	Requirement Reference	Compliant
BDA-FUN-01	The photometer angular response shall be described by a single-mode feedhorn.	IRD-DETP-R07	TBD
BDA-FUN-02	The spectrometer long-wavelength angular response shall be described by a multi-mode feedhorn. The spectrometer short wavelength angular response shall be described by a single-mode feedhorn (TBC).	IRD-DETS-R07	TBD
BDA-FUN-03	The spectral long-wavelength cutoff determined by the feedhorn output waveguide aperture will be located at the appropriate edge frequency.	IRD-DETP-R08 IRD-DETS-R08	TBD
BDA-FUN-04	The positional repeatability of the focal plane structure shall be < 125 um (TBC) orthogonal to the optical axis, and < 625 um (TBC) along the optical axis. The rotational repeatability around the optical axis shall be < 0.5 degrees (TBC).	JPL	TBD

Specification ID	Description	Requirement Reference	Compliant
JFET-FUN-01	The JFET module will mount to the Herschel optical bench, dissipating power to the level 2 stage of the cryostat.	IRD-FTB-R07 IRD-FTB-R05	Yes
JFET-FUN-02	The RF filters will operate without power dissipation	IRD-RFM-R03	TBD
JFET-FUN-03	The JFET modules must be capable of functioning, without meeting noise specifications, over a temperature range from 4 K to 300 K	IRD-FTB-R06	TBD
JFET-FUN-04	The JFET module and RF filters will	IRD-FTB-R08	TBD

	operate from a base temperature between 4 – 20 K.		

3.1.3 Technical specification

Note: For all budgetary resource values (mass; thermal dissipation; temperature) the instrument will hold a margin against the design value – 20% unless indicated otherwise. Where the minimum performance value is below the margin (BDA-TEC-06, JFET-TEC-05), a system level analysis will be conducted to investigate the effect of increasing the resource allocations to the minimum performance values indicated here. A future release of this document will reflect updated resource allocations and minimum performance levels.

Specification ID	Description	Requirement Reference	Compliant
BDA-TEC-01	The BDA shall accommodate a defined mechanical interface to the 2 K structure.	IRD-DETS-R08 IRD-DETP-R14 IRD-STRP-R01	Yes
BDA-TEC-02	The BDA shall provide an attachment point and/or a thermal interconnect to a 300 mK thermal strap.	IRD-STRP-R01	TBD
BDA-TEC-03	The BDA mass will have a design value of 600 g (TBC) average over 5 detector arrays, including output connectors.	IRD-SUBS-03	TBD
BDA-TEC-04	The first resonant frequency of the BDA will be > 200 Hz (TBC), with a goal of > 250 Hz.	IRD-DETP-R15 IRD-DETS-R16	TBC
BDA-TEC-05	The mechanical envelope of the BDA will be described by the ICD.	IRD-DETP-R12 IRD-DETS-R13	TBD
BDA-TEC-06	The total power dissipated onto the 300 mK cooler will be < 15 μW (minimum performance); < 8 μW (design value). Assumes the focal plane mount is held at 1.7 K.	IRD-DETP-R13	Minimum Value not compliant. Design Value is compliant.
BDA-TEC-07	The power allocated for temperature control of the 3He stage is 2 μW.		TBC

Specification ID	Description	Requirement Reference	Compliant
JFET-TEC-01	The JFET modules will have a mass less than 305 g.	IRD-SUBS-R03	TBD
JFET-TEC-02	The mechanical envelope of a JFET module will be TBD mm x TBD mm x TBD mm.	IRD-FTB-R04	TBD
JFET-TEC-03	The RF filters are to provide –40 dB attenuation from 500 MHz to 3 GHz (TBC, minimum), -60 dB attenuation from 500 MHz to 10 GHz (TBC, goal).	IRD-FTB-R02 IRD-RFM-R01	TBD

JFET-TEC-04	The first resonant frequency of a JFET module will be > 200 Hz (TBC), with a goal of > 250 Hz.	IRD-FTB-R09	TBD
JFET-TEC-05	The on-state power dissipation of a JFET module is to be < 11 mW (minimum performance); < 5.5 mW (TBC) (design value). This results in a photometer power dissipation < 66 (33) mW, a spectrometer power dissipation < 22 (11) mW, and an average dissipation < 44 (22) mW assuming 50 % operation of the photometer and 50 % operation of the spectrometer. NB: A 50% margin will be held on the design values to reflect the uncertainty in achieving the low thermal dissipation.	IRD-FTB-R05	Minimum Value not compliant Design Value is compliant

3.2 Operational Specification

3.2.1 Operational Safety

Specification ID	Description	Requirement Reference	Compliant
BDA-SAF-01	Failure of the BDA or JFET modules, or one of its components, shall not affect the health of any other subsystem, the instrument or the interface with the satellite.	IRD-SAFE-R07	TBC
BDA-SAF-02	Failure of any component of the BDA or JFET modules shall not damage any redundant or backup component designed to replace that component in the BDA or JFET modules.	IRD-SAFE-R08	TBC

3.2.2 Reliability

Specification ID	Description	Requirement Reference	Compliant
BDA-REL-01	Failure of BDA and JFET modules shall not lead to the total loss of instrument operations.	IRD-REL-R01	TBC
BDA-REL-02	Observations can continue in degraded mode in the event of failure of the cold beam steering mirror.	IRD-REL-R02	Yes
BDA-REL-03	Point source observations can continue in degraded mode in the event of	IRD-REL-R02	Yes

	misalignment of the photometer or spectrometer BDAs.		
BDA-REL-04	Single-point failures in the detector and JFET wiring (detector bias, JFET power) are to be duplicated. The RF filter module on these lines will also be redundant.	IRD-REL-R03	Yes
BDA-REL-05	BDA temperature stabilisation shall be implemented by an interruptible software-driven control loop.	IRD-REL-R04 IRD-REL-R05	Yes

3.3 Interface Requirements

3.3.1 3He Cooler

Requirement ID	Description	Reference	Subsystem Compliance
BDA-HCO-01	Detector performance requires a temperature < 290 mK (goal) delivered at the point of contact to the BDA. Design value sensitivities assume 300 mK at the detector.	IRD-COOL-R01 BDA-PER-02	TBC
BDA-HCO-02	Detector performance requires temperature stability at the point of thermal control (near the evaporator) of 10 uK/rtHz (TBC) from 0.1 – 10 Hz. This assumes that the BDA acts as a 100 s thermal low-pass filter.	IRD-COOL-R05	TBC
BDA-HCO-03	Maximum allowed thermal drift at the point of thermal control (near the evaporator) is 0.1 mK/hr (TBC). This assumes that the BDA acts as a 100 s thermal low-pass filter.	IRD-COOL-R04	TBC

3.3.2 Wiring Harness

Requirement ID	Description	Reference	
BDA-WIR-01	Wiring harness shall meet the specifications described in the IIDB.	IIDB	TBC
BDA-WIR-02	Wiring harness shall have a mechanical resonant frequency greater than 1kHz.	JPL	TBC
BDA-WIR-03	The EMC from the wiring harness shall be < TBD.	JPL	TBC

3.3.2 DRCU

3.3.2.1 Functional description

The DRCU provides amplification and digitization of the bolometer signals. Starting from the bolometer end of the signal chain, the detector is AC-biased by the DRCU in series with 2 x 10 MΩ cryogenic load resistors. The differential AC bias provides stabilization of the JFETs and amplifiers by modulating the signal above the electronics 1/f knee. The AC bias also reduces the 1/f noise requirements on the JFET amplifiers, allowing them to operate at the small power dissipation required by the Herschel cryogenic system. The differential bolometer signals pass to low-noise Si JFET amplifiers mounted on the Herschel optical bench. The JFETs provide power amplification by reducing the output impedance for ~ 5 MΩ to ~5 kΩ. Electrical power for the JFETs is provided by the DRCU, in addition to a controllable heater for JFET startup and noise optimization. The differential output signals pass through the cryo-harness to the LIA input stage of the DRCU. The LIA stage amplifies the bolometer signals and performs synchronous demodulation with the bias reference. An offset signal is removed from the output of the LIA so that the signals can be digitized with a 16-bit A/D converter, and the signals are muiltiplexed.

The bias generator, LIA signal outputs, and power supplies interface with a digital second stage. The digital second stage commands the amplitude and frequency of the bias, and sets the voltages for the JFET power supplies. The signals from the LIA stage are digitized by the second stage synchonously with the bias. The digitized signals then pass to the DPU for digital processing and storage for telemetry.

The design of the DRCU is modular so that the instrument may be run in photometer or spectrometer mode, operating only the spectrometer or photometer pixels. In addition, in photometer mode the DRCU is capable of amplifying 3 thermometers for thermal control of the 300 mK stage. A control signal can be generated to control the 300 mK stage temperature by means of a heater at the stage or elsewhere in the refrigerator.

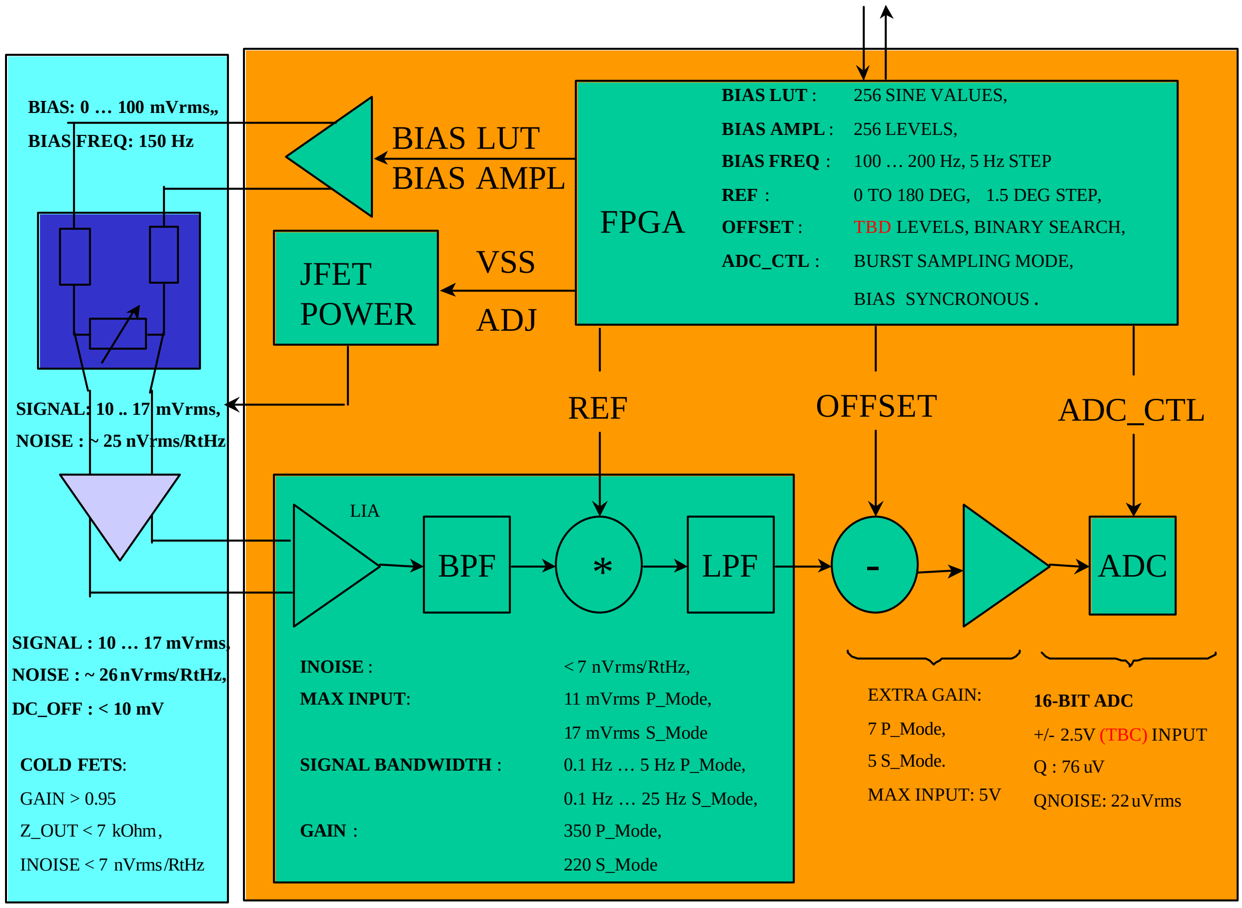
3.3.2.2 DRCU channel description

The detector subsystem requires the following channels:

Table 3-3-1 BDA Channel Description

Array	Opt. Pixels	Dark Pixels	Thermistors	5 MΩ Resistors
P/LW	43	2	2	1
P/MW	88	2	2	1
P/SW	139	2	2	1
S/LW	19	2	2	1
S/SW	37	2	2	1
T/C	0	0	3	0

3.3.2.3 Signal flow diagram



The design nominal and (peak of the load curve) signals are as follows:

Table 3-3-2 BDA Nominal Voltages (in mVrms)

Array	Opt. Pixels	Dark Pixels	Thermistors	Resistors	Bias Amp.
P/LW	3.7 (4.6)	5.4 (5.6)	3.2	3.2	16
P/MW	4.2 (5.2)	6.1 (6.3)	3.6	3.6	18
P/SW	4.7 (5.8)	6.8 (7.1)	4.1	4.1	20
S/LW	7.6 (9.4)	10.9 (11.4)	6.5	6.5	33
S/SW	6.3 (7.8)	9.1 (9.5)	5.5	5.5	28
T/C			100.0		500

3.3.2.4 Noise budget

The design noise budget is as follows:

Table 3-3-3 Nominal Noise* Budget (in nK/ÖHz)

	P/LW	P/MW	P/SW	S/LW	S/SW
Photon	21	25	29	25	29
Phonon	9	9	9	9	9
Johnson	7	7	7	7	7
Load resistor	2	2	2	2	2
JFET	7	7	7	7	7

LIA	6	6	6	6	6
A/D	4	4	4	3	3
Quad. Subtotal	26	29	33	29	33
Thermal+	< 6	< 7	< 8	< 12	< 11
EMI/EMC	< 5	< 5	< 5	< 5	< 5
Microphonic	< 5	< 5	< 5	< 5	< 5
Quad. Total	< 27	< 31	< 35	< 32	< 35

*Referred to the detector.
+T_n < 300 nK/√Hz at the detector.

3.3.2.5 Thermistor channels

The temperature sensitivity to base plate temperature of the thermistors is given by $T_n = V_n (dT/dV)$, where $dV/dT = (-\alpha V/T)*(2R_L/(R_B+2R_L))$, and $V_n^2 = V_{n,amp}^2 + 4kTR_B(1 + R_B/2R_L)$ The equivalent temperature sensitivity of a detector is given as $T_n = NEP/G_0$, where NEP includes all noise sources.

Table 3-3-4 Nominal Temperature Sensitivities in nK $Hz^{-1/2}$

Array	Thermistor T_n	Detector T_n
P/LW	330	1200
P/MW	300	1200
P/SW	260	1200
S/LW	165	700
S/SW	195	900

3.3.2.6 DRCU Requirements

Requirement ID	Description	Reference	Subsystem Compliance
BDA-DRCU-01	The DRCU signal processing electronics shall have less than 7 nV/rtHz as seen post demodulation, after digitzation. Noise is referred to the input over the frequency range 0.05 to 25 Hz. This performance must be accomplished with a bias input signal to the DRCU of 10 mVrms AC, 5 mV DC, 1 V DC common-mode offset, with an input load of 7 kOhms.	JPL	TBD
BDA-DRCU-02	The input noise impedance shall be greater than 7 kΩ, post-demodulation, referred to the input over the frequency range of 0.1 to 10 Hz.	JPL	Requirement deleted
BDA-DRCU-03	Input capacitance to be less than 100 pF.	JPL	TBD

BDA-DRCU-04	Input impedance to be larger than 1 MΩ.	JPL	TBD
BDA-DRCU-05	The DRCU is to provide 5 BDA bias signals, adjustable from 0 to 200 mV_{rms}, and 1 bias signal for temperature readout, adjustable from 0 to 500 mV_{rms}. The temperature readout biases are to be divided from a common oscillator. Each bias shall be adjustable with 8-bit precision. The frequency of each bias shall be adjustable between 30 and 300 Hz, with a precision of 5 Hz.	JPL	TBD
BDA-DRCU-06	The DRCU will provide 15 commandable JFET source voltages with 256 levels. The range of Vss is from 0 V to –5 V.	JPL	TBD
BDA-DRCU-07	Vdd is to be adjustable from 1.5 to 4 V.	JPL	TBD
BDA-DRCU-08	Vdd and Vss lines individually must source 1 mA to 5 mA. Noise on Vss < 1 μV/√Hz, and noise on Vdd < 0.3 μV/√Hz within modulated band (30 – 300 Hz).	JPL	TBD
BDA-DRCU-09	Each of the 15 Vdd and Vss levels must be commandable ON/OFF for spectrometer and photometer independently, without overshoot.	JPL	TBD
BDA-DRCU-10	The DRCU will provide 2 double-wired JFET heater lines with adjustable amplitude and duration. The supplies must be able to provide 5 V and 25 mA (photometer), 3 V and 10 mA (spectrometer). Each heater line is commandable ON/OFF.	JPL	TBD
BDA-DRCU-11	The common-mode rejection is –60 dB (30 – 300 Hz).	JPL	TBD
BDA-DRCU-12	The DRCU shall provide a dynamic range at the ADC sufficient to maintain the noise performance of the detectors under maximal signal conditions. This is estimated to be 16 ADC telemetry bits (TBC).	JPL	TBD
BDA-DRCU-13	The signal bandwidth of the photometer channels shall be 0.03 Hz to 5 Hz.	JPL	TBD
BDA-DRCU-14	The signal bandwidth of the spectrometer channels shall be 0.03	JPL	TBD

	Hz to 25 Hz.		
BDA-DRCU-15	The sampling of the photometer channels shall be synchronised with the bias, at a rate selectable between ν_{bias} to $\nu_{bias}/256$.	JPL	TBD
BDA-DRCU-16	The sampling of the spectrometer channels shall be synchronised with the bias, at a rate selectable between ν_{bias} to $\nu_{bias}/256$.	JPL	TBD
BDA-DRCU-17	The DRCU shall provide 2 adjustable power supplies for temperature control using a heater located at the 300 mK stage. This supply must provide at least 300 mV and 50 uA.	JPL	TBD
BDA-DRCU-18	Noise performance BDA-DRCU-01 shall be maintained under bias range 50 – 300 Hz.	JPL	TBD
BDA-DRCU-19	DRCU noise performance (BDA-DRCU-01) to be maintained under a warm electronics thermal drift of 1 K / hour (TBC).	JPL	TBD
BDA-DRCU-20	Thermal requirements on bias stability are implicit in BDA-DRCU-01.	JPL	TBD
BDA-DRCU-21	Thermal requirement on JFET power is dV/V < 500 ppm / K for Vdd and Vss.	JPL	TBD
BDA-DRCU-22	The DRCU shall not saturate at an input voltage as large as 11 (TBC) mV_{rms} at input (photometer), 17 (TBC) mV_{rms} at input (spectrometer). DRCU channels shall remain functional if one input signal goes to Vbias.	JPL	TBD
BDA-DRCU-23	Specification on isolation of power supplies, ripple, noise, EMC TBD. Specifications to flow from keeping the electrical interference and dissipation at the bolometer below fundamental noise as in Table 3-3-3.	JPL	TBD
BDA-DRCU-24	Bias, JFET power, and readout electronics for the spectrometer and photometer arrays are to run from separate dedicated power supplies, with independent, isolated grounds.	JPL	TBD
BDA-DRCU-25	The electrical cross-talk between channels in the DRCU shall be less	JPL	TBD

	than 0.05 % (TBC). The electrical cross-talk shall be verified by varying the input signal on one channel and measuring the response in other channels. The input signal level to each channel must be representative.		

3.3.2 Structures Specifications

Requirement ID	Description	Reference	Subsystem Compliance
BDA-STR-01	The structure interface shall provide compensation of the position and rotation of the BDA by TBD um in x and y, TBD um in z, and TBD degrees.	IRD-STRP-R03 IRD-STRS-R03	TBC
BDA-STR-02	The JFET modules will be housed in a JFET enclosure with a defined mechanical interface.	JPL	
BDA-STR-03	The BDA and JFET modules shall be housed in an RF-tight shield. All electrical, optical (TBC), and thermal penetrations into the shield will be RF blocked or attenuated. It shall be possible to electrically isolate the RF shield from the optical bench. The JFET modules form part of this RF shield. The defining point for electrical ground of the RF shield shall be at the 2 K boxes. The RF shield will attenuate radiated power by 40 dB (TBC) from 500 MHz to 10 GHz.	JPL	
BDA-STR-04	The wire-to-wire capacitance of the cables running from the BDA to the JFET modules will be < 50 pF (TBC), after mounting.	IRD-FPHR-R01	TBC
BDA-STR-05	The cables routed inside the structure shall be affixed to have a mechanical resonant frequency > 1 kHz (TBC).	IRD-FPHR-R02	TBC
BDA-STR-06	The radiated EMI onto the detectors shall be < TBD.	JPL	

3.4 Design and Manufacture Specification

Specification	Description	Requirement	Compliant

ID		Reference	
	BDA design		
BDA-DES-01	The P/SW array is to have 139 detectors operating at 250 um in a close-packed array of 2fλ feedhorns.	IRD-PHOT-R02 IRD-DETP-R07	Yes
BDA-DES-02	The P/MW array is to have 88 detectors operating at 350 um in a close-packed array of 2fλ feedhorns.	IRD-PHOT-R02 IRD-DETP-R07	Yes
BDA-DES-03	The P/LW array is to have 43 detectors operating at 500 um (TBC) in a close-packed array of 2fλ feedhorns.	IRD-PHOT-R02 IRD-DETP-R07	Yes
BDA-DES-04	The S/SW array is to have 37 (TBC) detectors operating between 200 and 300 (TBC) um in a close-packed array of 2fλ feedhorns at 250 um (TBC)	IRD-SPEC-R04 IRD-DETS-R07	Yes
BDA-DES-05	The P/LW array is to have 19 (TBC) detectors operating between 300 (TBC) um and 670 um in a close-packed array of 2fλ feedhorns at 350 um (TBC).	IRD-SPEC-R04 IRD-DETS-R07	Yes
BDA-DES-06	The photometer and spectrometer arrays shall be designed to accommodate coincident pixels for maximum point source sensitivity.	JPL	
BDA-DES-07	The BDA will accommodate cryogenic load resistors for current bias.	JPL	
BDA-DES-08	The BDA will provide electrical connector ports for ease of integration into the instrument.	JPL	
BDA-DES-09	The BDA will incorporate a differential design to minimize EMI/EMC and microphonic susceptibility.	JPL	
BDA-DES-10	The BDA and JFET assemblies shall be tested under a vibration level of 22 mm amplitude (5 – 24 Hz), 50 g amplitude (24 – 100 Hz), 0.1 g amplitude (100 – 400 Hz) at a sweep rate of 2 oct/min. TBC.		
	JFET module design		
JFET-DES-01	JFET modules shall accommodate up to 24 differential channels.	JPL	
JFET-DES-02	All JFET output lines will be RF filtered.	JPL	
JFET-DES-03	Each JFET input connector will provide 2 detector bias signals.	JPL	
JFET-DES-04	Each JFET module will accommodate cryogenic source resistors in order to minimise microphonics susceptibility.	JPL	
JFET-DES-05	The JFET unit shall incorporate a differential design to minimise	JPL	

	EMI/EMC and microphonic susceptibility.		
JFET-DES-06	Two RF modules will be incorporated into the JFET enclosure to filter detector bias, JFET power, and JFET heater lines.	JPL	

3.5 Logistic Requirements

The bolometer arrays will be delivered in nitrogen purged boxes for storage. As the detector arrays are nearly sealed from dust and contamination by the focal plane assembly, we place no cleanliness requirement during handling and installation. We assume there will be no need to disassemble the BDA once delivered to QMW. If that need arises, members from JPL must be present. The JFET units must also not be opened, and shall be handled using standard ESD practices.

3.6 Environment Requirements

TBW.

3.6.1 Natural environment

TBW.

3.6.2 Operating Environment

TBW.

3.7 Verification Requirements

Before delivery to the SPIRE BDA; JFET modules and RF filter modules will undergo environmental and performance qualification and acceptance. Several of these tests (e.g. EMI/EMC, thermal stability and microphonics) can only provide useful information at a higher system level, and will not require component-level testing. The following table lists the environmental tests for model delivered:

Test:	CQM	PFM	FS
Vibration:	**Q(TBC)**	**A**	**A**
Thermal cycle:	**D/Q**	**A**	**A**
Vacuum cycle	**D/Q**	**A**	**A**
Lifetime:	**D**	**-**	**-**
Soak/cycle:	**D (TBC)**	**-**	**-**
Radiation tolerance:	**D**	**-**	**-**
Thermal range:	**D**	**-**	**-**
Thermal stability (Instrument Level):	**Q (TBC)**	**A**	**A**
Microphonics (Instrument Level):	**Q**	**A**	**A**
Ionising radiation:	**D**	**-**	**-**
EMI (Instrument Level):	**Q**	**A**	**A**

EMC (Satellite Level):	**Q**	**A**	**A**

Table 3-1 : Test matrix for the BDA and JFET modules. Q indicates a test carried out at qualification level for qualification times; A indicates a test carried out at acceptance level; D indicates a qualification test carried out by design, including unit-level testing and engineering analysis. An X indicates that this test is carried out and is a characterisation type test or the level is irrelevant. A dash indicates that no test will be done on this model/unit.

Verification ID	Description	Reference
BDA-VER-01	To carry out the tests on the BDA QM listed in Table 3-1.	IRD-VER-R01 IRD-VER-R03
BDA-VER-02	To carry out the tests on the BDA PFM listed in Table 3-1.	IRD-VER-R01 IRD-VER-R04
BDA-VER-03	To carry out the tests on the BDA FS listed in Table 3-1.	IRD-VER-R01 IRD-VER-R04

APPENDIX 1: QUALIFICATION TESTS DESCRIPTION

Vibration:	The QM BDA will be vibrated at levels appropriate to its location within the instrument, as defined in AD2.
Thermal-Vacuum cycle:	The BDA and JFET modules will undergo thermal vacuum tests. According to standard JPL procedures, 3 times the number of lifetime thermal cycles will be imposed for qualification testing on representative units. For acceptance testing, the number of thermal cycles after delivery from JPL will be incurred.
Lifetime:	Lifetime tests to be carried out on all non-flight standard electrical components; novel materials and novel manufacturing processes. Details of tests to be determined on a case by case basis.
Soak/cycle:	Electrical soak test to be carried out on JFET modules at operating temperature followed by cycle to ambient temperature followed by soak test. Number of cycles and details of applied voltages etc to be defined.
Radiation tolerance:	Radiation tests will be to 20 krad TID. Components may be qualifed by analysis or independent testing.
Thermal range:	Need to test to bakeout temperatures to ensure survival of the detector subsystem units when the Herschel satellite is baked out.
Thermal stability:	A test designed to ensure the verification of detector operation if the interface temperature varies during operation. This may only be applicable at instrument level.
Microphonics:	Test to be performed at the systems level.
Ionising radiation:	The effects on the detector performance of individual ionising radiation impacts must be evaluated by modelling or tested for. This is NOT the same test as radiation tolerance, which only implies a total integrated dose. It is desirable that a high energy (>100 MeV) proton beam line is employed to carry out this test with a representative the detector cold and active.
EMI:	Test to be performed at the systems level.
EMC:	Test to be performed at the systems level.
Materials conformance:	All materials used in the manufacture will be approved for space use by ESA.