PFM S/SW BDA Compliance Matrix

Document Number: SPIRE-JPL-PRJ-002054

Issue: Final draft for JPL approval

Prepared by: Bruce Swinyard
Matt Griffin
Jamie Bock

Date: July 1 2004

Approved by:

James J. Bock SPIRE Co-Investigator Jet Propulsion Laboratory, Pasadena, USA
Martin Herman U.S. SPIRE Detector Project Element Manager Jet Propulsion Laboratory, Pasadena, USA
Eric Sawyer SPIRE Hardware Project Manager
Rutherford Appleton Laboratory, Oxfordshire, UK

Contents

1 Introduction

This document summarises the compliance of the SPIRE PFM S/SW BDA (as delivered) with the requirements as laid out in the Detector Subsystem Specification Document (BDA SSSD: SPIRE-PRJ-000456, Issue 3.2, Jan. 7 2003). It reproduces the relavant tables and notes from the SSSD with additional columns indicating compliance. Compliance may be by design (as documented in the DBA design documentation, by test (as reported in the EIDP) or by analysis (reported as indicated in the table). Requirements that require uinstrument-level verification are deemed non-applicable (N/A) for acceptance of the unit as delivered.

2 Compliance with specifications

2.1 Performance Specification

Specification ID	Description	Requirement Reference	Minimum Performance	Design Value	PFM S/LW BDA Compliance
BDA-PER-01	Maximum number of bad detectors in each BDA	IRD-DETP-R04 IRD-DETS-R04	11 (P/LW) 22 (P/MW) 35 (P/SW) 5 (S/LW) **9 (S/SW)**	4 (P/LW) 9 (P/MW) 14 (P/SW) 2 (S/LW) **4 (S/SW)**	Compliant by test. Two bad and one possibly bad pixels: • F4: Noisy pixel – noise level is so high that it is regarded as dead. • D5: dead pixel. • D6: bad BoDAC readout. Pixel likely to be OK; status to be established by instrument-level tests.
BDA-PER-02	The ratio of photon NEP due to radiation absorbed by the detector and total NEP, given as $(NEP_{photon}/NEP_{tot})^2$ NEP includes all sources of noise at 1 Hz, measured at 300 mK, assuming a total readout noise of 10 nV/√Hz and the values in Table 3-1-2.	IRD-DETP-R01	0.46 (P/LW) 0.53 (P/MW) 0.59 (P/SW) 0.50 (S/LW) **0.59 (S/SW)**	0.55 (P/LW) 0.63 (P/MW) 0.70 (P/SW) 0.60 (S/LW) **0.71 (S/SW)**	Compliant by test. Median value is 0.62
BDA-PER-03	The optical efficiency of the BDA horn and bolometer assembly for the photometer arrays over the optical passband. at the centre of the bandpass assuming ?[2] throughput and a beam filling source	IRD-DETP-R01	0.65	0.85	N/A

BDA-PER-04	The optical efficiency of the short wavelength spectrometer horn arrays and bolometer assembly at 250 µm assuming 2 ?^{2} throughput and a beam filling source and measured using an optical filter with a width of 15% of the central wavelength	IRD-DETS-R01 IRD-DETS-R08	-	0.7	Compliant by test. Measured pixels have optical efficiencies between 0.61 and 0.84, with a median of 0.70 Note: wording of this requirement (defined before JPL had done a full analysis of the feed and cavity) is regarded as inappropriate. Test was performed in a passband from waveguide cut-on to 255 µm (before the second mode enters). Calculated efficiency assumes single mode. Test passband included on CD data package.
BDA-PER-05	The optical efficiency of the long wavelength spectrometer horn arrays and bolometer assembly at 350 µm assuming 3?^{2} throughput and a beam filling source and measured using an optical filter with a width of 15% of the central wavelength	IRD-DETS-R01 IRD-DETS-R08	-	0.75	N/A
BDA-PER-06	The photometer detector time constant (based on a maximum modulation frequency of 2 Hz)	IRD-DETP-R02	32 ms	18 ms (P/LW) 13 ms (P/MW) 11 ms (P/SW)	N/A
BDA-PER-07	The spectrometer detector time constant (based on a maximum signal frequency of 20 Hz).	IRD-DETS-R02	14 ms (S/LW) **8 ms (S/SW)**	4.2 ms (S/LW) **4.2 ms (S/SW)**	All measured pixels have time constant = 5.36 ms. Median value is 3.9 ms.
BDA-PER-08	The uniformity of the calibrated responsivity.	IRD-DETP-R03 IRD-DETS-R03	0.99	0.99	Not characterised – to be veriefied at system level
BDA-PER-09	Detector cross-talk.	IRD-DETP-R05 IRD-DETP-R06 IRD-DETS-R05 IRD-DETS-R06	< 5 % nearest neighbors	1 % nearest neighbors 0.1% non-nearest neighbors	Not characterised – to be veriefied at system level
BDA-PER-10	The 1/f knee frequency (frequency at which		0.1 Hz	0.03 Hz	Compliant by test.

	total noise is √2 larger than white level).				Note: 1/f noise measurements were made under dark conditions for which appropriate bias was lower at 21 mV than for optical tests.
BDA-PER-11	The detectors shall be designed for optimal performance under the following levels of absorbed power (pW).	JPL		2.5 (P/LW) 3.3 (P/MW) 4.1 (P/SW) 10.6 (S/LW) **10.8 (S/SW)**	Compliant by design
BDA-PER-12	The detectors and readout electronics shall be designed to function under a radiation background a factor of two lower or a factor of 5 higher than the nominal values assumed in BDA-PER-11				BDAs compliant by analysis carried out by Matt Griffin and presnted at SPIRE IBDR, March 2002. DRCU design is capable of accommodating bolometer impedance from zero to max. (dark) impedance.
BDA-PER-13	The positional repeatability of the focal plane structure shall be < 125 µm orthogonal to the optical axis, and < 500 µm along the optical axis. The rotational repeatability around the optical axis shall be < 0.5 deg.	RAL		<125 µm orthogonal <500 µm along axis <0.5 degree rotation	Compliant by test

Notes:

BDA-PER-01: A "bad detector" is here defined as one that does not achieve, at the BDA output, performance compatible with the minimum performance values for BDA-PER-2 to 10.

BDA-PER-02: The bolometer performance estimation assumes the following nominal photon NEPs (W/√Hz) referred to power absorbed at the detector:

P/LW: 4.6×10^{-17}
P/MW: 6.3×10^{-17}
P/SW: 8.2×10^{-17}
S/LW: 10.5×10^{-17}
S/SW: 13.6×10^{-17}

BDA-PER-02 and BDA-PER-11: The optical loading and photon NEP assume the following nominal optical efficiencies of the bolometer and feedhorn combinations:

P/LW 0.65
P/MW 0.65
P/SW 0.65

S/LW 0.65
S/SW 0.70

BDA-PER-11: The values of optical loading are based on the SPIRE instrument sensitivity models, and incorporate the following assumptions:
(i) the thermal background from the telescope corresponds to a temperature of 80 K and an emissivity of 4%;
(ii) the total power loading on the detectors is dominated by the telescope, with a negligible contribution from the instrument itself;
(iii) the spectral passbands are defined by a combination of BDA waveguide cut-off and submillimetre filters resulting in a negligible contribution to the background and the NEP from out-of band radiation.

2.2 Functional Specification

Specification ID	Description	Requirement Reference	PFM SLW BDA Compliance
BDA-FUN-01	The photometer angular response shall be defined by a straight-walled conical feedhorn.	IRD-DETP-R07	Compliant by design
BDA-FUN-02	The spectrometer angular response shall be defined by a multi-mode feedhorn.	IRD-DETS-R07	Compliant by design
BDA-FUN-03	The spectral long-wavelength cutoff determined by the feedhorn output waveguide aperture will be 670 μm.	IRD-DETP-R08 IRD-DETS-R08	Compliant by design

2.3 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	PFM SLW BDA Compliance
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	Compliant by design
BDA-TEC-02	The BDA shall provide an attachment point and/or a thermal interconnect to a 300 mK thermal strap.	IRD-STRP-R01	Compliant by design
BDA-TEC-03	The BDA mass will have a design value of 600 gm averaged over 5 detector arrays, including output connectors.	IRD-SUBS-03	Compliant by design
BDA-TEC-04	The first resonant frequency of the BDA will be > 200 Hz, with a goal of > 250 Hz.	IRD-DETP-R15 IRD-DETS-R16	Compliant by qual unit test
BDA-TEC-05	The mechanical envelope of the BDA will be described by the *Detector Subsystem Interface Control Document* [RD5].	IRD-DETP-R12 IRD-DETS-R13	Compliant by design
BDA-TEC-06	The total power load on the 300 mK cooler from the BDAs will be < 15 μW (minimum performance); < 8 μW (design value). This assumes the focal plane	IRD-DETP-R13	Compliant by design. Note: measured heat

	mount is held at 1.7 K.		load of < 3.5 uW is an upper limit, intended to verify the unit does not have a cold touch. Dominant error is calibration of the fridge load at low applied power due to very long fridge time constant.
BDA-TEC-07	The power allocated for temperature control of the ^{3}He stage is 2 μW.		N/A

2.4 Operational Specification

Specification ID	Description	Requirement Reference	PFM SLW BDA Compliance
BDA-SAF-01	Failure of a BDA or JFET module, or one of its components, as tabulated in BDA-SAF-03 to 06, shall not affect the health of any other subsystem, the instrument, or the interface with the satellite.	IRD-SAFE-R07	Compliant by design
BDA-SAF-02	Any on-ground failure of a component of a BDA or JFET module will result in the entire module being removed and either replaced or refurbished at JPL at module level.	IRD-SAFE-R08	N/A
BDA-SAF-03	Separate sets of 2 x 3 overlapping photometer pixels that are to be used for chopped point source observations shall not be served by the same 24-channel JFET membrane. The particular pixel set to be designated as the redundant set will be specified by the SPIRE Project.		N/A
BDA-SAF-04	Any in-flight failure of any component of a BDA or JFET module shall not damage any redundant or backup component designed to replace that component. The only redundant hardware related to the BDA are bias and power wiring, RF filter modules, and back-up modules for the warm electronics.		Compliant by design of harness and electronics
BDA-SAF-05	The power supplies to each individual JFET 24-channel membrane shall be commandable ON/OFF (see BDA-DRCU-06)	IRD-SAFE-R07	N/A

2.5 Reliability

Specification ID	Description	Requirement Reference	PFM SLW BDA Compliance
BDA-REL-01	Failure of a BDA and a JFET module shall not lead to the total loss of instrument operations, as tabulated in BDA-SAF-03 to 04.	IRD-REL-R01	Compliant by design
BDA-REL-02	Observations can continue in degraded mode in the event of failure of the cold beam steering mirror.	IRD-REL-R02	Compliant by design
BDA-REL-03	Point source observations can continue in degraded mode in the event of misalignment of the photometer or spectrometer BDAs.	IRD-REL-R02	Compliant by design
BDA-REL-04	Single-point failures in the detector and JFET wiring	IRD-REL-R03	Compliant by

	(detector bias, JFET power) are to be duplicated. The RF filter modules on these lines will also be redundant.		design
BDA-REL-05	BDA temperature stabilisation shall be implemented by an interruptible software-driven control loop.	IRD-REL-R04 IRD-REL-R05	Compliant by design

2.6 Interface Requirements

Requirement ID	Description	Reference	PFM SLW BDA Compliance
BDA-HCO-01	Design values of detector performance requires a temperature < 290 mK at the point of contact to the BDA. Design value sensitivities assume 300 mK at the detector.	IRD-COOL-R01 BDA-PER-02	Compliant by design. To be confirmed by instrument-level testing of the CQM.
BDA-HCO-02	Design values of detector performance require temperature stability at the point of thermal control (near the evaporator) of 10 μK/√Hz from 0.1 – 10 Hz. This assumes that the BDA acts as a 100-s thermal low-pass filter.	IRD-COOL-R05 BDA-PER-10	N/A Compliance to be verified by instrument-level testing of the CQM.
BDA-HCO-03	Maximum allowed thermal drift at the point of thermal control (near the evaporator) is 1 mK/hr. This assumes that the BDA acts as a 100 s thermal low-pass filter.	IRD-COOL-R04 BDA-PER-10 BDA-HCO-02	N/A Compliance to be verified by instrument-level testing of the CQM.

2.6.1 Design and Manufacture Specification

Specification ID	Description	Requirement Reference	PFM SLW BDA Compliance
	BDA design		
BDA-DES-01	The P/SW array is to have 139 detectors operating over a band centred on 250 μm with λ/Δλ = 3, in a close-packed array of 2Fλ feedhorns.	IRD-PHOT-R02 IRD-DETP-R07	N/A
BDA-DES-02	The P/MW array is to have 88 detectors operating over a band centred on 350 μm with λ/Δλ = 3, in a close-packed array of 2Fλ feedhorns.	IRD-PHOT-R02 IRD-DETP-R07	N/A
BDA-DES-03	The P/LW array is to have 43 detectors operating over a band centred on 500 μm with λ/Δλ = 3, in a close-packed array of 2Fλ feedhorns.	IRD-PHOT-R02 IRD-DETP-R07	N/A
BDA-DES-04	The S/SW array is to have 37 detectors for FTS spectroscopy between 200 and 325 μm in a close-packed array of feedhorns with dimensions as given in Table 3-4-1.	IRD-SPEC-R04 IRD-DETS-R07	Compliant by design
BDA-DES-05	The S/LW array is to have 19 detectors for FTS spectroscopy between 315 μm and 670 μm in a close-packed array of feedhorns with dimensions as given in Table 3-4-1.	IRD-SPEC-R04 IRD-DETS-R07	N/A
BDA-DES-06	For all sets of detectors which are designed to overlap on the sky, the internal relative alignment of the corresponding feedhorn centres in the three photometer arrays or two spectrometer arrays shall be ± 40 μm (corresponding to a co-alignment accuracy of ±0.5" on the sky).	RAL	The S/SW and S/LW arrays both meet the 40 μm requirement. Compliance of

	"Internal relative alignment" here is defined as the alignment of the detectors wrt each other when the respective BDAs are optimally co-aligned at their mechanical interfaces in a manner consistent with BDA-STR-01.		co-alignment is to be achieved at instrument level.
BDA-DES-07	The BDA will accommodate cryogenic load resistors for current bias.	JPL	Compliant by design
BDA-DES-08	The BDA will provide electrical connector ports for ease of integration into the instrument.	JPL	Compliant by design
BDA-DES-09	The BDA will incorporate a differential readout scheme and harness design to minimize EMI/EMC and microphonic susceptibility.	JPL	Compliant by design
BDA-DES-10	The BDA assemblies shall be sine vibration tested at a temperature T < 90 K under the following qualification levels: a vibration input level at the base of 60 g between 5-100 Hz, or 11-mm amplitude at the base, whichever is less severe, at a sweep rate of 2 oct/min. Acceptance sweep rate is 4 oct/min. and acceptance amplitude is lower by 1.5. The BDA assemblies shall be random vibration tested at a temperature T < 90 K under the following qualification levels: The input spectrum for the BDA in any direction is: * 0.8 g^2/Hz between 100 and 300 Hz * Ramp-up between 20 and 100 Hz at +6 dB/oct * Ramp-down between 300 and 2000 Hz at -6 dB/oct The input to the BDA is allowed to be notched at resonance to a level equal in g rms to 100 g for the suspended mass, taking into account a 4-sigma variation of the measured rms signal, in order not to exceed a quasi-static equivalent loading of the BDA of 100 g. The notch width at full depth should not exceed 1/3 octave band-width, with a ramp-up and ramp down of 10 db per octave. If JPL experience major problems in maintaining the 100-g limit while keeping within the notching scheme as defined above, then the spectrum shall be revised by mutual agreement between JPL and the Project Team. Notes: 1. It is possible, but not certain, that the above levels may be relaxed in the future taking into account the responses of individual BDAs. 2. Acceptance levels are a factor of 2.25 (g^2/Hz) or 1.5 (g-rms) lower than qualification levels. Accordingly, for acceptance tests, the notched random vibration spectrum shall be such as not to exceed a quasi-static load of 100/(1.5) = 67 g. 3. Duration of tests: 120 seconds per axis qualification; 60 seconds per axis acceptance.	AD2	Compliant by test on qual. unit
BDA-DES-11	The BDA and JFET assemblies shall not exceed a temperature of 80 C and duration longer than a combined	JPL	N/A

	300 total hours during bakeout testing at component, instrument and spacecraft level. Note that a change in the maximum temperature in this requirement would result in a change in the duration.		

2.7 Feedhorn and Array Backshort Parameters

The tables below summarise the detailed specifications for the feedhorns and the detector backshort distances.

λ_o = Nominal band centre wavelength
λ_b = Wavelength for which bolometer backshort distance is optimised
λ_U = Nominal long-wavelength edge (defined by the waveguide diameter)
λ_L = Nominal short-wavelength edge (defined by edge filter in front of horn)
$\lambda_o/\Delta\lambda$ = Bandwidth assuming that an edge filter at exactly λ_L is in front of the horn
Defocus = Required position of focus with respect to the horn aperture. Note: this places a requirement on the position of the horn wrt the mechanical interface of the BDA, which is to be specified in the Interface Control Document, consistent with this table.

Tolerances quoted correspond to maximum and minimum values acceptable for any horn (not the rms of a set of horns).

Feedhorn and filter specifications for the spectrometer

FTS Bands		**Array**						
		S/SW			**S/LW (N/A)**			**Status with respect to specification**
Number of horns		37			19			Redundant with BDA-DES-04
l_o	mm	258			487			N/A
l_b	mm	275			450			N/A
l_L **(50% points)**	mm	190	+/-	2	300	+/-	3	N/A: Reported in Cardiff University Filters EIDP
l_L **(90% trans. points)**	mm	200	+/-	2	315	+/-	3	N/A: Reported in Cardiff University Filters EIDP
l_U	mm	321	to	329	666	to	683	Not measured.
l/Dl **(50% points)**		1.83	to	1.99	1.27	to	1.34	N/A (redundant with λ_U and λ_L.)
Horn length	mm	2368	+/-	200	4636	+/-	200	In spec. by design. Not measured directly. Note: Typo in BDA SSSD: 2368 and 4346 should read 23680 and 43460.
Horn centre-centre distance	mm	2250	+/-	20	3900	+/-	20	Not clear from data provided. Consequences: irrelevant, because primary requirement BDA-DES-06 is met.
Horn internal aperture	mm	2150	+/-	5	3800	+/-	9	Out of spec. All diameters are 10-20 µm larger than the nominal value of 2150 µm (EIDP pp108-109). Consequences: irrelevant – no significant impact on performance.
Waveguide length	mm	550	to	600	900	to	950	In spec. by design.

							Not measured.
Waveguide diameter	mm	188	to	193	390	to	400	Waveguide exits (EIDP pp. 103, 104): all in spec. except two slightly out: circles 31 (187.2 μm) and 36 (187.4 μm).
Defocus	mm	0	+/-	500	0	+/-	500	N/A
Backshort length	mm	69	+/-	7	113	+/-	11	All pixels in spec. except for three (DK2, D4, C3) with values of (80, 61, 61 μm) . DK 2 is dark, so spec. is N/A. Others are acceptable because the primary requirement on optical efficiency (BDA-PER-05) is met.

2.8 Verification Requirements

Verification ID	Description	Reference
BDA-VER-01	To carry out the tests on the BDA QM listed in SSSD Table 2-7-1.	IRD-VER-R01 IRD-VER-R03
BDA-VER-02	To carry out the tests on the BDA PFM listed in SSSD Table 2-7-1.	IRD-VER-R01 IRD-VER-R04
BDA-VER-03	To carry out the tests on the BDA FS listed in SSSE Table 23-7-1.	IRD-VER-R01 IRD-VER-R04

SSSD Table 3.7.1

Test	CQM	PFM	FS	PFM SLW BDA Compliance
Vibration:	**Q**	**A**	**A**	Waivers agreed by SPIRE Project on: (i) sine vibration as per HR-SP-JPL-RFW-005; (ii) only one minute random vibration duration as per test report W/O101369 in EIDP.
Thermal cycle:	**D/Q**	**A**	**A**	Compliant
Vacuum cycle	**D/Q**	**A**	**A**	Compliant
Lifetime:	**D**	**-**	**-**	N/A
Soak/cycle:	**D**	**-**	**-**	N/A
Radiation tolerance:	**D**	**-**	**-**	N/A
Thermal range:	**D**	**-**	**-**	N/A
Thermal stability (Instrument Level):	**Q**	**A**	**A**	N/A
Microphonics (Instrument Level):	**Q**	**A**	**A**	N/A
Ionising radiation:	**D**	**-**	**-**	N/A
EMI (Instrument Level):	**Q**	**A**	**A**	N/A
EMC (Satellite Level):	**Q**	**A**	**A**	N/A

Table 23-7-1: 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.