1. Introduction

The purpose of this document is to summarise and report on the status of the EMC test and analysis activities carried out on the SPIRE instrument and its constituent subsystems at the time of the PFM DRB.

2. Table of Contents

3. Change record

Date	Comments
16 March 2007	Sent skeleton document to Filippo for comment (0.1)
23 March 2007	Sent to Filippo for comment (0.2)
04 June 2007	Significantly updated (0.3) for telecon 04/06/07

27 June 2007	Updates based on comments from telecon of 04/06/07
26 July 2007	Issued

4. SPIRE EMC Documentation

4.1 Requirements

RD	Document	Comments
RD1	SCI-PT-IIDA-04624_4_0 – Herschel/Planck Instrument interface Document Part A	This is the source of the high level EMC requirements on the instrument and is the source of the test levels. The document also contains some requirements and recommendations on the EMC testing.
RD2	SPIRE-RAL-PRJ-000034 - Instrument Requirements Document	This places requirements on the grounding configuration of the instrument
RD3	SPIRE-JPL-PRJ-000456 - Herschel SPIRE Detector Subsystem Specification Document	The requirement “BDA-ISY-01” specifies the maximum power spectral density of EMI disturbances to the detector as well as the maximum rms EMI currents flowing through the detector

4.2 Subsystem EMC Documents

RD	Document	Comments
RD4	HSPIR-PSU-REE-DA0018814-V-ASTR Iss. 0 Rev 0.	QM HSPSU Test Report
RD5	HSPIR-PSU-REE-DA0018814-V-ASTR, Iss. 2 Rev 0	PFM HSPSU Test Report
RD6	HSPIR.PSU.PR.00049.V.ASTR, Iss. 2 Rev. 0	Test Plan EMC et ESD Equipement PSU SPIRE
RD7	SAp-SPIRE-DS-011-06, Iss. 1, Rev. 0	EMC Test report on FCU QM2
RD8	HERSCHEL SPIRE DPU PFM EMC TEST REPORT, HERS-SPIRE-RP-CGS-009, Iss. 1.0	PFM DPU Test report
RD9	Test Report CESI A6008140	RD8 references this.
RD10	Test report on the attenuation provided by the FPU and JFET RF filters	I do not have a copy of this report, but it exists.

4.3 Instrument Level Tests

RD	Document	EUT / Comments
RD11	SPIRE CQM-II EMC Test Report, SPIRE-RAL-REP-002167	Conducted susceptibility tests on CQM FPU + JFET + QM1 DRCU
RD12	SPIRE PFM3 EMC Test Procedure, SPIRE-RAL-PRC-002855	Procedure for both Conducted Susceptibility and simulation of the Radiated Susceptibility
RD13	SPIRE PFM3 CS Threshold EMC Test Report SPIRE-RAL-REP-002856	Results from Conducted Susceptibility Tests
RD14	SPIRE PFM3 EMC RS-Simulation Test Report SPIRE-RAL-REP-002858	Results for injecting currents onto the cryoharness
RD15	SPIRE PFM5 EMC Test Report SPIRE-RAL-REP-002852	Results from CS tests with variable amplitude modulation along with CE tests. The EUT was the PFM DRCU and FPU

4.4 System Level Tests

RD	Document	Comments
RD16	SPIRE EQM EMC Test Procedure SPIRE-RAL-PRC-002545	Instrument Test Procedure
RD17	PTR for SPIRE EMC Tests HP-2-ASED-MN-1140	EQM Test PTR for RS testing
RD18	TRR for SPIRE EMC Test HP-2-ASED-MN-1127	EQM Test TRR for RS testing
RD19	SPIRE EQM EMC Report SPIRE-RAL-REP-002577	SPIRE Test report
RD20	PLM EQM EMC Test Procedure HP-2-ASED-PR-0033	Astrium overall Test procedure
RD21	SPIRE STM2 Procedures SPIRE-RAL-PRC-002746	The SCOS 2K scripts
RD22	SPIRE STM2 EMC Test Procedure TEC-EEE/2006.62/FM	Instrument Test Procedure
RD23	Herschel STM2 EMC test TRR H-P-ASP-MN-8376	TRR for STM2 tests
RD24	Herschel STM2 EMC Test PTR MoM SCI-PT-44563	PTR for STM2 Tests
RD25	SPIRE STM2 EMC Test Report SPIRE-RAL-REP-002800	Test results

4.5 SPIRE Non-Conformance Reports and Requests for Wavers

This list is for information only and is not configured.

RD	Document	Comments
RD26	SPIRE EMC H-Field RS results ASED-NC-1800:	Not formally closed, but understood not to be problematic
RD27	SPIRE E-field RS results non conformance ASED-NC-1804:	Open – based on ~30MHz susceptibility
RD28	HSFCU : conducted emissions on primary powerlines exceeds IIDA limits HR-SP-CEA-RFW-004	DM OOL at 4.77 and 4.97MHz – closed
RD29	HSDCU : Susceptibility to E Field HR-SP-CEA-RFW-015	Susceptibilities at 215MHz and 185MHz – closed
RD30	HSDCU & HS_FCU : no radiated emission tests performed HR-SP-CEA-RFW-0 17	Tests to be conducted on QM DCU and FCU
RD31	Maximum sensibility for TC notch increase in EMC measurements HERS-SPIRE-RFD-CGS-001	Waiver on the emissions within the TC notch
RD32	Limit Violation of Conducted Emission on Input Power Line, Differential Mode NCR-SPIRE-CGS-007	DM OOL @ 65 kHz
RD33	Conducted Emissions on Primary Power Lines, Frequency Domain, Differential Mode, NB HERS-SPIRE-WV-CGS-002	Waiver raised as a result of NCR-SPIRE-CGS-007. Accepted

4.6 Other documents

RD	Document	Comments
RD34	SPIRE EMC Update Meeting Jan 2007, SPIRE-RAL-MOM-002854	Reports on the discussion of the revision of the susceptibility of SPIRE under in-band amplitude modulation of the EMI
RD35	SPIRE Design Description SPIRE-RAL-PRJ-000620, Iss 2.0	Contains a design description of the detector chain and some information of EMC coupling mechanisms.
RD36	SPIRE EMC Compliance Review, SPIRE-RAL-MOM-002718, August 2006	These are the minutes of a review meeting held at RAL between SPIRE, ESA and Industry to review the qualification status of SPIRE
RD37	Introduction To EMC Techniques For Herschel Instrumentation - SAp-SPIRE-DS-0000-02	Written by CEA
RD38	Grounding and Screening Philosophy SPIRE-RAL-PRJ-00624	
RD39	SPIRE EMC Control Plan SPIRE-RAL-PRJ-000852	
RD40	Herschel Payload EMC Testing SCI-PT/013216	Includes a useful summary of the RE measured in a range of recent ESA missions

5. Overview of EMC requirements

The main requirements for the EMC performance of the instrument are enumerated in RD1 which define the levels and spectrum for radiated (E and B-Field) and conducted (Differential and Common mode) emission and susceptibility limits. The requirements on emission define the maximum tolerable level of EMI disturbance from SPIRE while requirements on susceptibility define the levels of EMI which must not degrade the performance of SPIRE. These emission and susceptibility limits are set so that there will be sufficient margin during system level tests and in flight to ensure that no EMI problems are encountered. Over and above these requirements focused on the scientific performance of the instrument, there are several requirements to ensure that SPIRE will be able to survive various fault conditions (ESD, shorts in the PCDU).

The derived EMI requirements for the SPIRE detector system are contained in RD3 (BDA-ISY-01). These requirements allocate budgets for both steady-state heating of the detectors (actually rms current in the detector) and excess noise within the detector signal bandwidth. In the context of a SPIRE EMC review meeting in Jan 2007, these budget figures were re-interpreted on the basis of an assessment of the nature of noise coupling into the detector signals via amplitude modulation of the EMI radiation (see RD34). This assessment concluded that the original requirements were overly stringent.

Requirements and recommendations on the procedures for EMC qualification of the instrument are contained in RD1. These requirements call for 1 kHz amplitude modulation of the disturbance for the conducted susceptibility tests above 50 kHz and above 14 kHz for the E-Field radiated susceptibility tests. The rationale for this is to induce some spreading of the spectrum of the disturbance in the frequency domain to make the disturbance more representative of flight like conditions. Under agreement with ESA, the disturbance signals were modulated at 1 Hz over the entire test spectrum for several tests rather than at the specified 1 kHz. The rationale for this was that it was a reliable means of circumventing the ambiguity between EMI on the detectors and thermal drifts/transients in the test cryostats. Any heating of the detectors from EMI currents would have a strong spectral component at 1 Hz from the modulation of the disturbance which would be easily distinguishable from thermal transients in the cryostat which would have a much lower frequency spectral distribution.

6. SPIRE EMI Susceptibility

6.1 Review of coupling mechanisms

SPIRE is an imaging photometer and spectrometer working in the sub-mm wavelengths. The detectors are NTD bolometers and operate at around 300mK. The detectors are voltage biased with an AC signal (50-300Hz). The signals from the detectors are buffered by JFET amplifiers close to the detectors and readout by lock-in amplifiers. The JFET amplifiers provide sufficient power to drive the signals along the cryoharness (~5000mm length). A series of filters within the lock-in amplifiers limit the detector bandwidth to 0.1-5Hz for the Photometer and 0.1 to 25Hz for the Spectrometer. In addition to the low frequency filtering in the back end electronics, the detector signal and bias lines together with the sub-system harnesses are all filtered by feed-through pi filters with an attenuation of > 40 dB between 500MHz and 3GHz.

EMI currents and voltages injected into the detection chain can induce spurious signals on the detectors by (1) heating the detectors, (2) changing the gain of the readout amplifiers, (3) inducing a differential signal on the signal lines within the detection bandwidth, or (4) through CM to DM conversion of the signals which is not adequately rejected by the readout electronics. The EMI can enter the instrument via radiative coupling to the harnesses or via EMI on the power interfaces. More detail on this is given in RD35.

7. Summary of conducted tests

7.1 Subsystem tests

7.1.1 DPU

A comprehensive qualification test (CS and CE) on the primary power interface on the PFM DPU was carried out (see RD8) by CGS. The differential mode emissions at 65 kHz were non compliant and an NCR (RD32) and an RFW (RD33) were raised. The disposition of the NRB was to accept the RFW, primarily on the basis that the non compliance was minor.

7.1.2 DRCU

Qualification tests (CS and CE) on the primary power interface on the PSU were carried out on the QM and FM PSU (see RD4 and RD5) by Astrium Toulouse. The differential mode emissions at around 5MHz were non compliant and an RFW was raised (RD28). The disposition of the NRB was to accept the RFW.

7.2 Instrument level tests

7.2.1 CQM-2

Conducted susceptibility testing was carried out on during the CQM2 test campaign. The test configuration for this test was deficient, in that the grounding of the instrument was not sufficiently representative of the flight environment. Although DM and CM susceptibilities were identified during this test, the results were considered suspect due to the poor grounding configuration. It was decided that the tests would be repeated in subsequent test campaigns. The tests are documented in RD11.

7.2.2 PFM3 Tests

The PFM FPU and JFET modules together with the QM2 DRCU and QM DPU were used to carry out what was intended to be the formal conducted susceptibility test (against IID-A CM and DM NB frequency domain) disturbances on the FCU primary power lines. These tests are documented in RD12 and RD13. The tests were carried out with 100% amplitude modulation of the disturbance at 1Hz and showed that the instrument was susceptible to both common mode and differential mode disturbances. The instrument was more susceptible to differential mode disturbances than common mode. Figure 1 shows the frequencies where SPIRE was found to be susceptible along with the threshold voltage below which the induced EMI signal PSD is below the noise floor of the detector and the number of dB the system is out of specification (based on 20 log (EMI / Requirement)).

Mode	Frequency	PLW	PMW	PSW
DM	2.48 MHz	79 mV / 16.0dB	71 mV / 17.0dB	67 mV / 17.5dB
	3.67 MHz	92 mV / 14.7dB	77 mV / 16.2dB	86 mV / 15.3dB
	5.40 MHz			
	9.27 MHz			
	11.25 MHz			
	16.17 MHz			
	20.10 MHz			
	28.25 MHz		24 mV / 26.4dB	31 mV / 24.2dB
	36.67 MHz			
	37.92 MHz	33 mV / 23.6dB	29 mV / 24.7dB	26 mV / 25.7dB
CM	6.00 MHz	425 mV / 4.4dB	460 mV / 3.7dB	431 mV / 4.3dB
	8.50 MHz			
	9.50 MHz			
	15.30 MHz	486 mV / 3.3dB	603 mV / 1.4dB	639 mV / 0.9dB
	20.00 MHz			
	34.00 MHz	720 mV / 0.2dB	687 mV / 0.2dB	732 mV / 0.3dB
	39.00 MHz			
	47.60 MHz	749 mV / 0.5dB	634 mV / 0.9dB	606 mV / 1.3dB

Figure 1 – Summary of the list of susceptible frequencies and threshold measurements for CS tests in PFM3 ILT test campaign.

7.2.3 PFM5 Tests

The conducted emissions were measured on the prime PFM PSU with the PFM instrument in ILT configuration (RD15). These tests were to act as a diagnostic of the EMC performance of the integrated SPIRE instrument and give confidence that deficiencies in test setup were not responsible for the EMC compliance issues of SPIRE. The results were broadly in line with the PSU subsystem tests.

During the SPIRE EMC meeting in Jan 2007 (c.f. RD34) it was agreed that the CS tests should be repeated. One of the aims of these tests would be to characterise the behaviour of the instrument when being subjected to AM disturbances of varying depth and modulation frequency. It was hypothesised that the CS susceptibility threshold of SPIRE would depend on both the frequency and amplitude modulation of the EMI source. Furthermore, if the frequency of the modulation of the disturbance was outside the detection band of SPIRE, then no susceptibilities would be seen and similarly if the depth of modulation were small, then no EMI would be detected.

The results of the tests are documented in detail in RD15. In summary, it was shown that in general the low pass filters in the detector readout electronics are effective in rejecting the EMI disturbances modulated outside of the detector bandwidth[1]. It was also demonstrated that the level of EMI depends linearly on the depth of modulation of the disturbance and effectively disappears when the EMI is un-modulated. An anomaly was found in the behaviour of the PMW detector array under DM CS disturbances whereby significant noise at ~1.5Hz was present on the signals irrespective of the frequency or depth of modulation. If this level of noise was found in flight conditions, then the scientific performance of the array would be severely degraded rendering them almost useless in comparison with the other arrays. There seems to be a correlation between the susceptibility and two PCB boards (PCB SN23 and PCB SN35). No difference in the manufacturing or nominal noise/power performance of these two boards has been identified and the mechanism for this different performance remains unidentified.

It is noteworthy that there is insignificant spread (of the order of ±15%) in the response of the detectors to EMI disturbances.

7.3 System level tests

The CE/CS and inrush currents were not measured during the EQM or STM2 test campaigns.

7.4 System Assessment

7.4.1 Conducted Emissions

The results of the subsystem and system conducted emissions tests indicate that no open issues remain regarding the CE performance of SPIRE.

7.4.2 Conducted Susceptibility

Apart from the anomalous behaviour of the PMW array seen in PFM5 test, the overall results indicate that the all the following conditions must be met to make SPIRE susceptible to conducted EMI at IID-A qualification levels:

1. The carrier frequency of the disturbance must be within a band where SPIRE is susceptible to EMI. The frequencies where the susceptibility is most severe for these bands are listed in Figure 1. It should be noted that the frequency range of susceptibilities is not reported in this table. The estimated width of the susceptibilities is of the order of F/ΔF ~ 10.
2. The disturbance must be amplitude modulated within the SPIRE detection band (Phot:<5Hz and Spect:<25Hz). The mechanism proposed for this are (a) beating of DC/DC converter clocks between two different subsystems, (b) beating of signal and digital circuitry clocks and (c) effects from switching loads. Regarding the firs and second mechanisms, the DC/DC converter clocks on Herschel are free running and it is therefore unlikely that two clocks are within ±25Hz (for the spectrometer detectors). Regarding the third mechanism; the loads drawn by the spacecraft subsystems are generally stable during normal operation and are therefore unlikely to cause interference to the SPIRE detectors. When a subsystem is switched off /

[1] The bandwidth of the photometer detectors is 0.03 to 5Hz (4dB/decade roll off) and 0.03-25Hz (6dB/decade roll off)

on then the load on the PCDU will change and it may cause a disturbance within the signal band of SPIRE. However these event are rare and could be correlated with spacecraft telecommands and de-glitched from the science data products without serious degradation of the scientific performance.

3. The amplitude of the carrier frequency of the disturbance ***and*** the depth of modulation of the disturbance must both be of sufficient amplitude to affect the detector signal. For example, during the PFM3 tests, it was found that the most susceptible detector array was PSW at a frequency of 37.92MHz where the susceptibility threshold was found to be ~26mV rms when modulated at 100%. If the depth of modulation were reduced to 20%, this threshold would rise to 130mV (i.e. a factor of 5). Similarly, lowering the modulation depth to 10% would raise the susceptibility threshold to ~200mV rms (i.e. a factor of 7.5).

Given that these three conditions must all be met, it is considered that the immunity of the SPIRE system is has been shown to be acceptable for the PSW and PLW arrays. The susceptibility thresholds indicated in RD13 were predicated on non-flight representative test conditions (100% AM with the SPIRE detector band) and can therefore be relaxed by a factor of at least five.

No explanation can be found for the anomalous behaviour of the PMW array during the PFM5 test. As this behaviour was found after the completion of the ILT testing, there has not been a further opportunity to experimentally investigate the problem. If it is seen in flight, then the scientific performance of the array will be serious affected. It is therefore recommended that CS testing be carried out at the earliest opportunity during the spacecraft system level tests.

The reader is referred to consider the note in §8.4 of this document which makes a comparisons between the conducted and radiated susceptibilities.

8. Summary of radiated tests

8.1 Subsystem tests

8.1.1 DPU

The tests did not reveal any non-compliances for RE/RS and ESD, although it should be noted that the ambient noise levels in the EMC facility in the 30Hz-50kHz band for H-Field tests was above the required RE limits and therefore a small level of doubt exists as to their validity in that a RE non-compliance of the DPU could theoretically be masked by the emissions from the facility.

8.1.2 DRCU

No RE tests have been carried out on the DRCU. This is to be carried out on the QM2 model of the DRCU after delivery of the PFM DRCU.

Three non-compliances were found for RS:

1. Photometer mode / E-Field / 210-220MHz with maximum susceptibility at 214.8MHz / Horizontal polarization / threshold of 6dB below applied incident power
2. Spectrometer mode / E-Field / 182.2-188.7MHz with maximum susceptibility at 184.9MHz / Horizontal polarization / threshold of 11dB below applied incident power
3. Spectrometer mode / E-Field / 704.0-714.6MHz with maximum susceptibility at 707.5MHz / Horizontal polarization / threshold of 5dB below applied incident power

The disposition on these non compliances is “us as is” (RD29) and the susceptible frequencies related to the geometry of the EUT.

8.2 CQM

The CQM FPU together with the QM1 DRCU (including bench power supply) were tested for E-Field and H-Field RS in a modified version of the ISO cryostat (see RD19). Susceptibilities were identified in both the E-Field and H-Field tests (see RD26 and RD27).

Frequency	Threshold (where measured)
~136Hz	
~262Hz	78.1 dBpT
~395Hz	
~533Hz	
~655Hz	80.1 dBpT
~1.28kHz	
~1.46kHz	83.3 dBpT
~2.29kHz	
~2.92kHz	81.5 dBpT
increasing between 4-50kHz	93.4 dBpT @ 50kHz

Figure 2 – Susceptible frequencies and thresholds for EQM H-Field tests

The principal frequency of the E-Field susceptibility was found to be ~32MHz with a secondary (weaker) susceptibility at ~16MHz. The susceptibility threshold was found to be in the order of 10mV/m for the worst five channels of the PLW array @ 32.4MHz. The susceptibility of the detectors follows a square law dependency (i.e. halving the applied field strength reduces the EMI on the signal by a factor of four).

There was no correspondence between the E-Field susceptibilities seen in the DRCU sub system tests and the EQM results even though the DRCU used in the EQM programme was non flight representative with degraded shielding on the chassis.

8.3 STM2

System level EMC tests were carried out with the CQM FPU and the QM2 DRCU which is flight representative. The main purpose of this test was to test the effectiveness of capacitive filters on the inputs to the DRCU amplifiers and ferrite filters on the cryoharness (See RD25). The susceptibility threshold found during these tests repeated the results from the EQM programme (~10mV/m susceptibility @ 30.9MHz). It was found that the filters and harness ferrites provided little or no improvement in the susceptibility threshold.

A test was carried out where the disturbance was not modulated at 1Hz. This was done in order to determine if (1) excess noise is seen on the detector signal when the amplitude of the disturbance is kept constant (i.e. no AM) and (2) perform a detector load curve with and without EMI injection which would act as a diagnostic of the coupling mechanism of the EMI. It was found that the detector noise floor was not affected by the presence of constant amplitude interference. It was also found that a small amount of detector heating was induced (~01.-0.2pW) by the EMI.

A histogram of the level of induced EMI signal on the detector shows that the level of susceptibility varies significantly across the array. The worst seven channels show and order of magnitude higher susceptibility threshold than the remaining 34 functioning detectors in the array.

8.4 System Assessment

Programme	E-Field strength in the 10-100 MHz Band	
	dBuV/m	**mV/m**
SAX PFM	30-55	1-316
ISO FM	30-40	1-10
Cluster PFM	30-45	1-32
Artemis	30-70	1 to 10000

Table 1 -Summary of E-field strength measured during system EMC testing of some recent ESA programmes in the 10-100MHz band.

The system testing to date indicate that EMI signals in the 30MHz band are picked up in the detector and induce heating of the detectors. The arguments listed in §7.4.2 regarding the necessary conditions for conducted EMI to be a problem in flight apply equally to radiated EMI. The level of susceptibility to B-Fields and the expected levels in flight indicate a positive margin and therefore it is unlikely that it will cause any problems.

Note: One feature of the RS when compared with the CS is that there is a far greater spread in the susceptibility threshold for the RS than the CS where all channels behave similarly. This indicates that there is a fundamental difference in the coupling of the EMI into the detector system for the two test configurations.

9. Recommendations for Spacecraft System Level EMC Testing

- Carry out CS testing on the PFM at the earliest opportunity to see if the PMW behaviour is real
- Perform the RS testing without 1Hz amplitude modulation of the disturbance
    - Carry out one test with 1Hz modulation so that we can know before launch which detectors are most likely to be susceptible to EMI in flight. (the information could be useful in the data analysis)
-