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Title	**HIFI OD81 anomaly investigation summary report**		
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Draft 11	02-11-2009	All	New document
Draft 12	05-11-2009	All	Comments LCU team incorporated
Draft 13	06-11-2009	All	Editorial changes

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1 INTRODUCTION

This report shows the results of investigations performed by the HIFI investigation team into the anomaly of the HIFI-LCU aboard the Herschel spacecraft that occurred Herschel operational day 81 on the 2ND of August, 2009. Investigations included analyses, tests and rationales. Detailed reports of all findings are included. Conclusions and recommendations are given, based on the results of the investigations.

2 SUMMARY AND CONCLUSIONS

Reconstruction of the HIFI anomaly showed that the fault signature has the following signature has the following characteristics:

- The LCU was found in a state with low power consumption drawing 0.36A primary supply current.
- During the sequence of events eventually leading to the LCU fault, communication was lost and I/F power was lost only 1.6s later.

Initial evaluation showed that only a failure of DCDCHRS4 in combination with the LCU standby relay in standby position can explain the low power consumption as observed. This therefore implies that the standby relay must have been switched in the sequence of events.

Detailed circuit design analysis and testing on the LCU IMD-3 model showed:

- One failure in 68 components (60 active + 8 passive) in DCDCHRS4 explains the power consumption as recorded.
- 18 of the identified active components are from the type 1N5819 (Schottky diode).
- It is confirmed that 16 diodes from the 18 type 1N5819 are stressed beyond the absolute maximum ratings (45V) during steady state operations due to pulses at a frequency 60KHz and with of 50nsec.
- Only for the diodes operation beyond maximum ratings has been identified. No other LCU component is found to be operating outside the ratings.
- The pulsed load on the diode is intrinsic to the design and can not be avoided.
- Planned switches, such as band switching and nominal to standby, produce an overshoot on the primary input voltage to a level up to 29V thereby increasing the stress on the diode significantly at a peak level up to 58V.
- An unplanned switch from nominal to standby produces an overshoot on the primary input voltage to a level up to 31V resulting in peaks up to 62V and brings the diode in reverse breakdown condition. The worst-case overshoot on the primary input voltage of 31V stays within the specified limits.
- So far the number of planned switches in the HIFI mission was approx. 4000 leading to 8000 overshoots in the diode. HIFI has seen so far only one unplanned switch from nominal to standby.

Component evaluation on the 1N5819 (Schottky diode):

- There is no evidence that the components inhibit a reliability problem. However, the diodes may degrade or fail due to the way they are operated and their load in the LCU application.
- Component testing confirms that the devices are more robust than estimated (even under severe overload). Literature on similar components supports this observation.
- As a result of the diode characteristics, a cold start of the LCU may bring the diodes in reverse breakdown conditions.
- It is noted that increasing the unit temperature to avoid reverse breakdown will lead to a load increase on other components, see also unit level LCU-NCR-34.

Analysis and testing of the LCU logic/Software confirmed the following:

- The effect of bit-flips in the memory has been tested and 5-10 out of ~300 locations are identified where a single bit results in loss of communication and a standby pulse after 1.3-1.6 sec.
- Single Event Upset (SEU) analysis confirms that, in worst case, once per 5 days an energetic particle could cause a bit flip in the memory. However further analysis on the likelihood that a SEU leads to this specific failure effect results in a large spread in outcome; ranging from once per year to once per 700 year. Still this is considered to be very unlikely.

Most likely scenario (due to the lack of a likely scenario, the only remaining but unlikely scenario becomes the likely):

- A single event upset corrupted the memory.
- The bit-flip brought the micro controller in non-communicado conditions.
- The micro controller jumped to an erroneous program location and started executing program code not intended to be used during normal operation
- After 1.6 sec. the standby relay was switched bringing the unit from full operational in standby.
- The resulting voltage transient on the internal 28V bus is fatal for a secondary rectifier diode type 1N5819.
- The ultimate situation is an instrument in stand-by, with loss of communication and drawing around 0.36A of current.

Operational hours:

- Up until the in-orbit failure, the prime LCU passed 6597 operational hrs. At the end of HIFI instrument level testing, 30 diodes type 1N5819 were replaced. This includes the 16 diodes, D20-27, D40, D41, D46, D47, D50-53 that are marked as candidates causing the failure. The operational hours of the replaced ones are 2579 hrs till 2^{nd} of August.
- Up until the 2^{nd} of August, the redundant LCU passed 660 operational hrs. No diodes have been replaced in the redundant DCDCHRS4 converter.

It is clear that 1N5819 diodes are operated outside the maximum ratings. This implies that there is no product data available supporting the actual operational domain or clear acceleration factors needed to determine the lifetime expectations. Literature on similar devices indicates that the capabilities of the diodes are significantly higher than assumed. Still a limited test program is started.

3 RECOMMENDATIONS

Regarding use of the prime and redundant LCU units we observe the following:

- Useful operation of HIFI is only possible by switching to the redundant chains
- Further attempts to switch the prime chains on again seem pointless
- Since damage of other DC-DC converters than HRS-4 can not be excluded and in the absence of analogue HK for monitoring purposes it advised not to undertake further activities on the prime LCU unit for the time being
- In view of the proposed scenario it is recommended to make an impact assessment for the LO chain band and review the band 7b commissioning approach in view of these findings.

To minimize the pulsed-stress conditions on the secondary rectifier diodes of the redundant LCU unit it is recommended:

- To prevent an instantaneous switch from nominal operation to standby through the standby relay
- To minimize the number of nominal transitions to LSU subband 0 and (present) LCU standby mode
- To operate the LCU in the temperature range between 10° en 30°C and explicitly avoid a cold start

Regarding the LCU software the following recommendations are made:

- Introduce regular/periodic checksum calculations to monitor the LCU memory integrity
- Consider to disable or eliminate the function switching the standby relay
- Keep the LCU software changes limited and small carefully trading off risk and benefit

HIFI reliability is reduced due to this diode problem and the fact that only one unit is left implies that there are now many single point failures in the system. It is furthermore unknown whether or not a diode degradation mechanism is at play under the identified pulsed-stress operating conditions and to what extent transients due to switching and mode transitions might accelerate such a process. Consequently it is not possible to recommend whether or not HIFI should be switched off or simply left switched on when not used for collecting scientific data. Since we can not exclude limited lifetime for the remaining HIFI mission we therefore recommend to prioritize science and make as efficient scientific use of HIFI as possible harvesting key science first and as soon as possible.

4 EVENT RECONSTRUCTION

4.1 LCU Anomaly 2009-08-02 T22:43:00Z

During DTCP of August 3rd (OD81) the LCU was found in an unknown mode 14 since 2009-08-02 T22:43:00Z. From that moment on no response from the LCU to periodic HK requests (therefore filled in by ICU as 0xEEEE) and commands was received anymore. The LCU, LOU and LSU temperatures started to drop immediately. Spacecraft heaters were switched on in an attempt to compensate the temperature when dropping below limits. The primary supply current dropped from 2.5A, corresponding to nominal operation of the LCU, to 0.36A from one to the next periodic HK reading, whereas the primary supply voltage remained constant all the time. The active band at the time of anomaly was band 7b tuned at a frequency of 1893.16 GHz in an on-the-fly mapping observing mode. Inspection of the periodic LCU HK revealed that the LO power dropped from one to the next HK reading leaving the HEB mixer in an unpumped state. The drop in LO power was also confirmed by the HRS 3P3 current HK reading which is indicative of the IF power level of the mixer which in turn depends on the LO power received by the mixer. Just prior to the anomaly the conditions at the LO hardware were completely stable (at the bit resolution level), reflected by very stable LCU analogue HK readings, primary supply current readings as well as HEB mixer and HRS 3P3 current HK readings. No action directed to the LO chain was going on at the time of the anomaly.

4.2 LCU Switch-off 2009-08-04 T15:20:00Z

During DTCP of the 4th of August 2009 (OD83) the LCL for the LCU was opened removing the primary power from the unit. This was done in between the switching points of the thermal regulation cycle of the spacecraft. From the LCU and LSU temperature profiles with respect to time it was concluded that the dissipation of the LCU as well as the LSU had dropped. When switching the LCU off the HRS 3P3 current increased from 2.2 to 2.6A yielding a yellow flag for the HRS. This was recognized and followed up later and discussed with the HRS team. The increase of 3P3 current was assigned to the loss of the 10 MHz reference signal supplied by the LSU. On the 6th of August the HRS-H and –V were switched off as well. HIFI was hence left in a hybrid state with the all units powered except for the LCU, LSU and HRS.

4.3 HIFI Switch-off 2009-08-07 T15:15:00Z

For spacecraft thermal management reasons it was finally decided to switch off HIFI entirely during DTCP of the 7th of August (OD86). The final LOU, LCU and LSU temperature levels showed to be consistent with the values observed during the initial switch-on of HIFI after launch on May 24th.

4.4 Initial Evaluation LCU Power Consumption

Using the refurbished QM model of the LCU (IMD-3) an initial evaluation of the power consumption of the electronic modules was made in order to explain the low primary power consumption of the LCU. The details of these tests are described in RD8. The main conclusion was that only a failure in DC-DC convertor HRS-4 would explain such low power consumption. Simulating a failure in HRS-4 and switching the LCU off and on again showed that the communication would be restored, analogue HK would be missing (zero readings, fixed raw values ADC) and a current below 0.4A would be drawn.

4.5 HIFI Restart 2009-08-10 T15:30:00Z

During DTCP of August 10th (OD89) a HIFI restart attempt was made. After closing the LCL for the LCU the primary supply current stabilized at 0.34A. The 10 MHz reference supplied by the LSU re-appeared reflected by the expected drop in the HRS 3P3 currents. Communication was fully restored and the LCU was found in standby mode as is expected after the boot. The LCU checksum was in agreement with the expected value for the firmware (0x8D04) loaded from the on-board PROM confirming the integrity of the LCU memory. The analogue HK values were zero with a fixed raw value of 0x4000 in agreement with a non-powered ADC.

4.6 Timing reconstruction

In addition to the periodic HK, collected every 4s, a number of specific HK readings from the LCU were made as part of the observing mode at the time of the anomaly. At the start of each spectrometer integration a specific sequence of LCU commands and HK requests was sent to fill the start-frame packet of the science data. It was found that communication was lost before power was lost. The moment where communication was lost could be confined to a time interval of 6 ms connected to the execution of a specific command (F30A CC7A) and following housekeeping request (B33A).
Making use of the data collected by the HIFI backends in the integration interval where loss of RF power took place it could furthermore be reconstructed that permanent loss of communication happened 1.6s before RF power was lost. The whole sequence of events connected to the LCU anomaly therefore started with loss of communication and only 1.6s later RF power was lost.

4.7 Key Symptoms of the anomaly

Reconstruction of the anomaly showed that the failure scenario must be consistent with all of the following key symptoms:

- After the anomaly the LCU was found in a state with low power consumption drawing 0.36A primary supply current
- After the anomaly the LCU was found in a state where the standby relay had been switched
- During the sequence of events eventually leading to the LCU failure communication was lost and only 1.6s later the RF power was lost.

5 FAULT INVESTIGATION

5.1 Hardware

5.1.1 Design and analysis

A Failure Mode and Effects Analysis (FMEA) was made that focused on the main effects seen in the LCU failure in the mission (see RD3). These main effects are:

- Failure of DCDCHRS4 converter with low input current (below 100mA)
- Unintentional switching to stand-by mode, i.e. switching off 4 other dc/dc converters in the LCU
- The interruption of communication with the ICU

The FMEA included the effects of LCU interfaces as well as environmental conditions (temperature, radiation). The FMEA shows that there is a group of component failures that may cause the failure effect for the HRS4 converters as observed in the mission. This group contains all secondary rectifier diodes, the UC1825 PWM controller and some resistors and capacitors.

The failure of the DCDCHRS4 converter has been analyzed in several ways:

- Design inspection by dc/dc converter experts from ESA (Ferdinando Tonicello) and JPL (Ted Fautz)
- Part stress analysis by JPL (see RD4) with comments from B.J. van Leeuwen (see RD5)
- Simulation by SRON-Utrecht (Martin Frericks, see RD6)

There are no written reports from the design inspections, but several tests have been performed to (dis-) qualify the suggestions from these inspections (see a.o. RD14).

5.1.2 Test and evaluation.

Extensive testing has been performed with several purposes. The main purposes are:

- to verify if the anticipated effects (or the lack thereof) of various failures indeed occur in practice
- to verify electrical conditions (voltages, currents) for several components and/or units
- to investigate the unspecified reverse voltage characteristics of the 1N5819 diodes

Reports of these tests can be found in section 9.

The following describes the major results of tests and analysis related to each of the three main failure effects as seen in the mission.

<u>Findings related to the HRS4 failure</u>

Design inspection (by Ferdinando Tonicello) and subsequent tests have revealed that a group of diodes, type 1N5819, are subject to electrical conditions that exceed their absolute maximum ratings. There are 16 diodes in the HRS4 dc/dc converter and 4 in the DCDC2 converter. All diodes in the HRS-4 converter are secondary rectifier diodes that were identified in the FMEA as possible causes of the failure effect as observed in the mission. The 16 diodes in the HRS4 converter are: D20-27, D40, D41, D46, D47 and D50-53. No other components have been found with any electrical or thermal stresses outside acceptable ranges.

The 16 diodes in the HRS4 converter are nominally subjected to reverse voltage peaks of ~54V, while their absolute maximum reverse voltage is specified as 45V. The duration of the voltage peaks is ~50nsec at a repetition rate of 65KHz (0.3% duty cycle). The voltage peaks are caused by ringing of a resonator consisting of (parasitic) leakage inductance from the transformer and diode capacitance.

These voltage peaks clearly exceed absolute maximum ratings; therefore degradation and/or failure of them is conceivable. One cannot conclude that a diode that failed in the HRS4 converter (supposing this is indeed the case) must have been a 'weak' part.

The level of the peak voltage only depends on the input voltage of the HRS4 converter. This voltage is usually 27V due to voltage loss across cables and LCU Ripple Filter. An overshoot on the HRS4 input voltage occurs when the current drawn by the LO subsystem changes significantly (i.e. my mode switching, band change, etc). Generally these overshoots are about 2V, only in case of a sudden transition from nominal to stand-by mode the overshoot can be as high as 4V. The voltage peaks across the diodes reach 58V or 62V respectively.
Tests performed on a limited number of diodes shows an average reverse breakdown voltage of 59V, so it is likely that breakdown occurs during such changes in LO subsystem activity. Breakdown is considered as the primary cause for damage and ultimately failure of these diodes.
Note that reverse breakdown threshold voltage was found to increase with temperature. This suggests that operation at higher temperature could be beneficial for diode lifetime expectation. Be aware that reverse leakage current also increases with temperature. Leakage current for this type of diode is substantial and causes additional dissipation. Operation at lower temperature is thus preferred from leakage current point of view.

Findings related to the unintentional switching to stand-by mode
Test and analysis have shown that a component failure or a SEU in the interface circuits could have caused this transition (toggle of relay position), but this is unlikely. The transition is therefore probably the result of an unintentional action by the microcontroller in the LCU.

Findings related to the loss of communication with the ICU
The loss of communication is probably also due to the microcontroller in the LCU. Since the communication was restored after power down, component failure can be excluded. SEU in the interface circuits is also not likely; it would cause false data, no total interruption.

General
No hardware test has reproduced the full sequence of events as seen in the mission. No failure mode was found that could explain all phenomena, including causes outside the HIFI instrument. Therefore it seems not very likely that the full sequence of events was initiated by a component or hardware failure mode.
Until now there is only one scenario to explain the full sequence of events. Since the LCU IMD-3 converter we tested does not fail for any transient or even for input voltages up to 45V dc, this scenario could not be fully demonstrated.

5.2 Software

5.2.1 *Objectives*

The software investigation (RD2) concentrated on the following items:

- routines in the LCU software that invoke the standby relay
- identification of program execution paths taking 1.58s before switching the standby relay
- possible ways to loose communication

5.2.2 *Standby relay*

It was found that only a limited number of software routines actually invoke the standby relay:

- in the start procedure (software reset) which is initiated when:
  - the LCU is powered on
  - executing a reset command from the ICU
  - returning from an undervoltage protection (emergency shutdown) interrupt service

- in the undervoltage protection (emergency shutdown) interrupt service
- in the procedure of executing the standby command from the ICU (standby transition)
- in diagnostic testing procedures still present in the program memory but not being used

5.2.3 Delay between loss of communication and power

Only the start procedure takes appreciable time to execute and could contribute significantly to the 1.6 delay between Loss of Communication (LoC) and Loss of Power (LoP). This procedure takes about 1.2 to 1.3s during which the LCU firmware in the PROM is copied into RAM and the standby relay is switched in the end. The other routines would drop the LO power immediately and would require the delay of 1.6s to be built up somewhere else prior to their execution. It was identified that also in the drain overcurrent interrupt service routine significant time could be built up in the case of repeating or intermittent (spurious) overcurrent signals. This would however not lead to switching the standby relay.

5.2.4 Loss of communication

Regarding the loss of communication many analyses and tests have been executed trying to simulate permanent loss of communication. Only in two cases permanent loss of communication was demonstrated:

- When the 28V voltage is interrupted (removed) internally for a specific duration such that the system restarts. This is however not compatible with the 1.6s delay between LoC and LoP as the undervoltage protection interrupt service would have acted immediately removing the LO power with virtually with zero delay. Moreover the LCL would have tripped in view of the required duration.
- When the program makes an unexpected “jump to zero”. If program execution somehow jumps to address zero, the start procedure is being executed, which leads to a switch of the standby relay after 1.2 to 1.3s, but in this case also to permanent loss of communication.

During the confined time interval where loss of communication was observed either a command was being handled or a HK request was being executed. A detailed analysis of the code and subroutines executed as part of handling the command (F30A CC7A) and the HK request (B33A) was made. In the code related to handling the command a memory area was identified whose corruption could lead to an unexpected jump in the program eventually leading to a jump to zero. Single bit-flips in that memory were simulated by patching the LCU software and executing the command and HK request sequence. 42 single bitflips cases were found that lead to the observed sequence of permanent loss of communication and a standby relay switch after more than one second. The statistics also show that in 6 individual bit-flip cases both the observed sequence as well as the 1.6s delay between LoC and LoP can be reproduced.

Investigations into the code executed during handling the HK request are still ongoing. It will furthermore be assessed how general the issue of unexpected jumps due to a bit-flip might be for the entire LCU code in order to estimate the probability of a SEU eventually leading the an unwanted jump to zero and standby relay switch.

Independently a number of scenarios have been evaluated in which multiple or repeating interrupts might lead to unexpected behaviour of the software. Interference between interrupt handling of different kind can be discarded, the LCU software appears furthermore robust against simultaneous interrupts of the same kind. Also cases of repeating interrupts do not lead to the observed behaviour.

5.2.5 Conclusion

Given present knowledge the only plausible mechanism found to permanently loose the communication and in turn switch the standby relay is due to a single event causing a bitflip in the memory area occupied by the program code handling LCU commands, in specific the code handling the command F30A CC7A.

6 OPERATIONAL LIFE, ENVIRONMENT AND COMPONENT

6.1 Operational life

6.1.1 Operational hours

LCU prime

Up until the in-orbit failure, the unit passed 6597 operational hrs. As a result of two NCR's on unit level, 30 pieces Schottky diodes, type 1N5819, were replaced at the end of HIFI instrument level testing. The operational hours of the replaced ones are 2579 hrs till 2^{nd} of August. The 16 diodes marked in RD1 as possible causes for the power conditions as observed during the failure, are also replaced. These 16 diodes are: D20-27, D40, D41, D46, D47, D50-53.

LCU redundant

Up until the 2^{nd} of August, the unit passed 660 operational hrs. No diodes have been replaced in the DCDCHRS4 converter.

6.1.2 Mode transitions

During the operations of the prime LCU about 4000 events leading to significant transients are recorded. The origins of those events are; band switching, nominal to standby (planned) etc. Each event results in two overshoots on the internal 28V line of 2V. This gives in total 8000 overshoots of 2V, each lasting about 1msec.
The nominal "internal 28V voltage" is 27V due to losses in the cables, LRF, etc. The peak voltage on the sixteen 1N5819 diodes mentioned previously, is 54V under nominal conditions, as determined experimentally on IMD-3. The peak appears to be 2 times as high as the nominal internal 28V due to design of the converter and parasitic resonances of the diode capacity and transformer inductance. A 2V overshoot will therefore result in peaks up to 58V on the devices.
The average breakdown voltage of the 1N5819 diodes is 59V at room temperature (measured on 5 devices). Breakdown will therefore occur for some diodes during this transient

An unplanned switch from nominal to stand-by due to switching the standby-relay, results in a overshoot of 4V. The peak voltage on the devices is 2x(27+4)=62V resulting in a breakdown current to 0.1A.
This transition has occurred once and should bring most diodes in breakdown condition.

6.2 Environment

6.2.1 Radiation

Regarding SEU; the key components in the DCDCHRS4 converter are UC1825 and UC1901. Although the upset rates for both devices are very low (order 2.4x 10-3 per year), SE conditions have been induced on devices in the IMD-3 model and showed no significant change in circuit behavior.

On the basis solar activity, orbit and spacecraft shielding, an analysis for SEU is performed on the most sensitive components in the digital section resulting in worst case estimates of:

- HM65656 memory: one SEU every 5 days
- 80C32E micro-controller: one SEU every 70 days

The effect of bit flips in the memory has been tested and ~40 out of ~800 locations are identified where a single bit results in loss of communication and a standby pulse after 1.3-1.6 sec.

At present it is unsure how to interpret this result:

- If we assume that all memory contents have the same probability to cause the observed effects, then the probability for the observed effect due to SEU will be once per 0.5-1 year.
- If we assume that these 5-10 locations are the only places in the memory where a bit flip will cause the observed effect, then the probability will be once per 700 years
- It seems that the observed effect can only be caused by a bit flip in a (conditional) jump instruction, followed by some rather specific jump addresses. Assuming that jump type instructions make up 10/256 of the total instructions and that the specific jump addresses make up 10/256 of the total addresses, then we find a probability of once per 9 years

The above probabilities are based on a SEU rate of once per 5 days, so the worst case.
The probability that the loss of communication and the switching of the stand-by relay are caused by SEU is very low.

6.3 Component testing

6.3.1 Temperature effects on 1N5819 diode behavior

11 devices were characterized on leakage current and avalanche breakdown versus temperature. The devices under test were taken from the two actual flight lots supplied by TL and IGG:

- Avalanche breakdown current is the main current for the measurements at higher reverse current and at lower temperatures. In the range of +20…+50C we find a positive temperature coefficient of the avalanche breakdown threshold of 30…50mV/ºC
- The reverse breakdown voltage threshold is between 58 and 61V at RT
- Leakage current increases with temperature. Its effect is mostly dominant at the measurements with lower reverse current and at higher temperatures.

Marginal difference in behaviour is observed between both component groups.
It is noted that increasing the unit temperature to avoid reverse breakdown will lead to a load increase on other components due to unit level LCU-NCR-34.
As a result of the diode characteristics, a cold start of the LCU may bring the diodes in reverse breakdown conditions.

6.3.2 Step-stress

On both component and IMD-3 unit level, tests are performed which fit the profile of step-stress.

<u>Pulsed stress test</u>
At component level, devices of the TL/IGG flight lot have been tested at the ESTEC facility under repetitive pulsed current stresses of up to 250mA with "mild" rise time below 1.5microseconds. With the pulse length being extended to 1.5 and 2microseconds, the self heating of the diodes leads to current leakages and – if the pulse length is extended - finally to a steep current increase prior to reaching breakdown voltage condition. Simultaneously, the breakdown voltage drops to 30-45V. No degradation or failures are recorded.

<u>Inductive pulse test (Schottky killer test)</u>
Single inductive pulsed current stress testing with 10-20ns rise time and 10A (!) current peak at 60V reverse voltage could not destroy the first test device. Repetitive inductive pulsed current stress testing with 10-20ns rise time and 1A peak current (0,8A average during 500ns, peak at 60V reverse voltage could not destroy the device during several minutes of test. No failures are recorded.
General observation is that the diodes are much more robust that expected.

IMD-3 unit level

On unit level, the peak voltage and current on D25 (1N5819 diode) is characterized towards various voltages on the unit 28V input line.

A diode peak voltage of 58.4V and a peak current of 120mA (indicating avalanche condition) are observed at 30V input voltage. Further increase of input voltage to 45V showed 59.2V and 420mA on the diode. No failure of the relevant component is observed.

6.3.3 Endurance:

It is clear that 1N5819 diodes are operated outside the maximum ratings. This implies that there is no product data available, supporting the actual operational domain or clear acceleration factors needed to determine the life expectations. Literature on similar devices indicates that the capabilities of the diodes are significantly higher than assumed. Still a test program is started.

Test conditions:

- Steady state voltage of 32V to pre-bias
- Instantaneous current peaks (<20ns rise time) of 0.5A to 1A by releasing the energy of a pre-charged inductor, to pulse stress the diodes at a frequency of 60kHz
- 5 devices of IGG lot for at least 500hrs

Note that this test is still ongoing. At the time of writing the test has run for 400 hrs without indications of changing diode characteristics.

7 ANNEX 1, DETAILED EVENT ANALYSIS RESULTS

Ref.	Title:	Doc. Number:
RD1	Observations during the LCU events	SRON-G/HIFI/RP/2009-040
RD2	LCU Software Investigation Report	SRON-G/HIFI/RP/2009-039

8 ANNEX 2, DETAILED DESIGN ANALYSIS RESULTS

Ref.	Title:	Doc. Number:
RD3	Observations during circuit analysis	SRON-U/HIFI/TN/2009-001
RD4	Parts Stress Analysis of Diodes and FETs in LCU DCDC4hrs	JPL/HIFI/RP/2009-004
RD5	Recorded communications towards the PSA; rpjpl2009-004a	
RD6	HIFI LCU closed loop simulations	SRON-U/HIFI/RP/2009-006
RD7	Circuit Model Stability Analysis LCU DCDC4hrs	JPL/HIFI/RP/2009-005

9 ANNEX 3, DETAILED TEST RESULTS

Ref.	Title:	Doc. Number:
RD8	FHLCU FM failure investigations done on IMD3 in Groningen, August 2009	SRC/LCU/PR/2009-0754
RD9	FHLCU FM failure investigations done on IMD3 in Groningen, September	SRC/LCU/PR/2009-0755
RD10	FHLCU FM failure investigations done on DIGIT_FS in Warsaw, October 2009	SRC/LCU/PR/2009-0756
RD11	FHLCU FM failure investigations: the possible compensation of primary current rapid decrease	SRC/LCU/PR/2009-0757
RD12	Observations during testing on IMD-3:	SRON-U/HIFI/TR/2009-001
RD13	Several tests on LCU-IMD3, performed from 2-9 September 2009	SRON-U/LCU/TR/2009-001
RD14	Several tests on LCU-IMD3, performed from 21-23 September 2009	SRON-U/LCU/TR/2009-002
RD15	Several LCU tests 8-9 October 2009	SRON-U/LCU/TR/2009-005
RD16	Worst case converter stability	----

10 ANNEX 4, COMPONENT-, ENVIRONMENT-, LIFETIME EVALUATION RESULTS

Ref.	Title:	Doc. Number:
RD17	Static temperature test of several 1N5819 diodes	SRON-U/LCU/TR/2009-003
RD18	Pulsed stress test on JANS1N5819-1 Schottky diodes	SRON-U/LCU/TR/2009-004
RD19	Converter Improvement Using Schottky Rectifier Avalanche Specification	APPLICATION NOTE AN2025
RD20	514 Reply Heterodyne Instrument Herschel UC1825	----
RD21	HIFI operational hours based on FPGA inventory	SRON-U/HIFI/TN/2007-001
RD22	HM65656, 80C32E, SEU rates on HERSCHEL	----