SESAME Flight Software User Manual

Flight Software Version FM-2

Software Release Notes Version FM 2.0

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Document History

Issue	Rev.	Date	Description of Change
02	Draft / 1	03. Aug. 2007	First draft based on the FM-1 Software User Manual; **provisional document ID RO-LSE-UG-3401, issue 2**
02	Draft / 2	20. Nov. 2007	Included comments by K. Gusbeth, K. Seidensticker and K. Thiel: Corrected CASSE Burst Mode TM format table; minor changes in several chapters.
02	Draft / 3	22. Jan. 2008	Changed text in CASSE_HC and CAS_MES TM format table. Added clarification of TM format in case of CASSE fatal errors (chap. 5.2).
02	Draft / 4	13. Feb. 2008	Clarification of PP_PM2 TM format; corrected CASSE Triggered Mode and Burst TM tables (after input from J. Durand and D. Popescu, CNES)
02	Draft / 5	30. April 2008	Corrected table of error codes in error messages.
		24. Sep. 2008	**New document ID RO-LSE-UG-3402**
01	0	24. Sep. 2008	Minor changes in various chapters.

Table of Contents

Referenced / Applicable Documents

Title	Code	Version	Date
CDMS Subsystem Specification	RO-LCD-SP-3101	4.5	13. Sep. 2002
ROSETTA Lander Common DPU (FM), User's Manual	RO-LCO-PR-3304	-	July 2000
SESAME Flight Software Specification	RO-LSE-DS-3401	4.1	15. May 2001
ROSETTA List of Acronyms	RO-LSE-LI-3003	7.1	5. Jan. 2002
SESAME Operations Plan A, Modes Timeline and Requirements	RO-LSE-PL-3102	1.0	31. Dec. 1998
SESAME Flight Software Quality Assurance Plan	RO-LSE-PL-3401	1.0	30. Mar. 1999
SESAME Software, Forth Coding Rules and Style Conventions	RO-LSE-PR-3401	1.1	28. May 1998
Software User Requirements	RO-LSE-RD-3401	1.0	27. July 1999
SESAME Cruise Phase Report	RO-LSE-RP-3102	PC6	9. Nov. 2007
CASSE Software Description	RO-LSE-SP-3420	3.0	15. June 2000
DIM Software Description	RO-LSE-SP-3440	4.0	25. Jan. 2001
Clarification of DIM Software User Requirements – Addendum to RO-LSE-SP-3440	-	4.0	24. July 2007
PP Software Description	RO-LSE-SP-3460	2a	8. Sep. 2004
SESAME E-Box Specification	RO-LSE-SP-3802	2.2	6. Feb. 2001
SESAME Flight Software, Science Data Compression with ESTEC-1	RO-LSE-TN-3401	1.2	3. Mar. 1999
Housekeeping Procedure	RO-LSE-TN-3402	2.5	4. May 2004
Interaction of SESAME with other Lander Units	RO-LSE-TN-3403	4.1	24. Jul. 2006
PP Basic Algorithms and Software Test	RO-LSE-TR-3460	1.0	26. July 2007
Flight Software User Manual, Issue 1: Software version FM-1.0	RO-LSE-UG-3401	1.2	10. Aug. 2001
CASSE FM PCB User Guide	RO-LSE-UG-3821	1.1	8. Dec. 2000
HS-RTX2010RH Programmer's Reference Manual, Harris Corporation	-	Draft	1991
LMI Forth-83 Metacompiler Manual, Laboratory Microsystems Inc.	-	3.0	1997
LMI UR FORTH Manual, Laboratory Microsystems Inc., 1997	-	-	1997

1 Scope

The present document describes the SESAME flight software, which is used to command and control the SESAME instruments CASSE, DIM, and PP and to deliver their measuring data. It explains the basic principles and provides detailed information for the maintenance of the flight software and the continuation of the iterative software development process. Apart from programming details, which are primarily interesting for the software developer, operational aspects are covered. All implemented telecommands and the telemetry formats are summarized in a separate chapter.

Note:
After several years of successful operation (on ground and in flight) of flight software version FM-1 a major revision of the software code was done. The present document describes features of the new software version FM-2. Please refer to the FM-1 flight software user manual (RO-LSE-UG-3401) for a description of software version FM-1 and the corresponding command and data formats.

The first release FM-2.0 of the revised software was uploaded to the SESAME instrument in space during Philae payload checkout #6 (September 2007). Please refer to the "Software Release Notes Version FM-2.0" (chapter 6 of the present document) for particular properties of release FM-2.0 (e.g. constraints, known problems). The release notes also include a list a major differences to the former software version. Further releases of software version FM-2 (if any) will be documented in separate release notes.

2 Conventions used in this Document

Source code is given in fixed-width, bold type, e.g. **`AddRequest ( n -- erc)`**. SESAME Style and Naming Conventions for FORTH Words are given in the Coding Rules and Style Conventions Guide (RO-LSE-PR-3401).

The present document provides information about software written in FORTH. The term “word” has a special meaning in FORTH: it describes entries in the FORTH dictionary. FORTH Words can be very different objects, which would be called e.g. number, operator, subroutine (or procedure) or program in higher programming languages. Although FORTH does not distinguish, concise terms are used, whenever it serves comprehension. Especially the term “routine” is used as an analogy for subroutine or procedure. A routine may take parameters from the stack and leave parameters on the stack after its execution, e.g. **`AddRequest ( n -- erc)`** takes the parameter n and leaves erc on the stack. Parameters are called input or return parameters of the routine, respectively, and the phrase “The routine returns ...” is used, e.g. **`AddRequest`** returns **`erc.`**

Data Structures
A byte contains eight bit (0 .. 7), with bit 0 being the least significant bit (LSB) and bit 7 the most significant bit (MSB). A word contains 16 bit (0 .. 15), with bit 0 being the LSB and bit 15 being the MSB. A word is composed of two byte, the low byte (bit 0 .. 7) and the high byte (bit 8..15).

Used acronyms are explained in the SESAME acronyms list (RO-LSE-LI-3003).

3 Hardware Environment

The SESAME H/W consists of the Central Electronics (CE), which is installed in the Y-electronics box (YEbox) of Philae, and the peripheral devices of the instruments CASSE, DIM, PP. The sensors and transmitters of the instruments represent one end of the SESAME H/W, the other end is the interface board of the Central Electronics. It connects SESAME to the data lines of the central control unit of the Lander called CDMS (Command and Data Management System) and to the power supply. The Central Electronics can be further divided into the Common Electronics and the instruments boards. The SESAME block diagram is shown in figure 1.

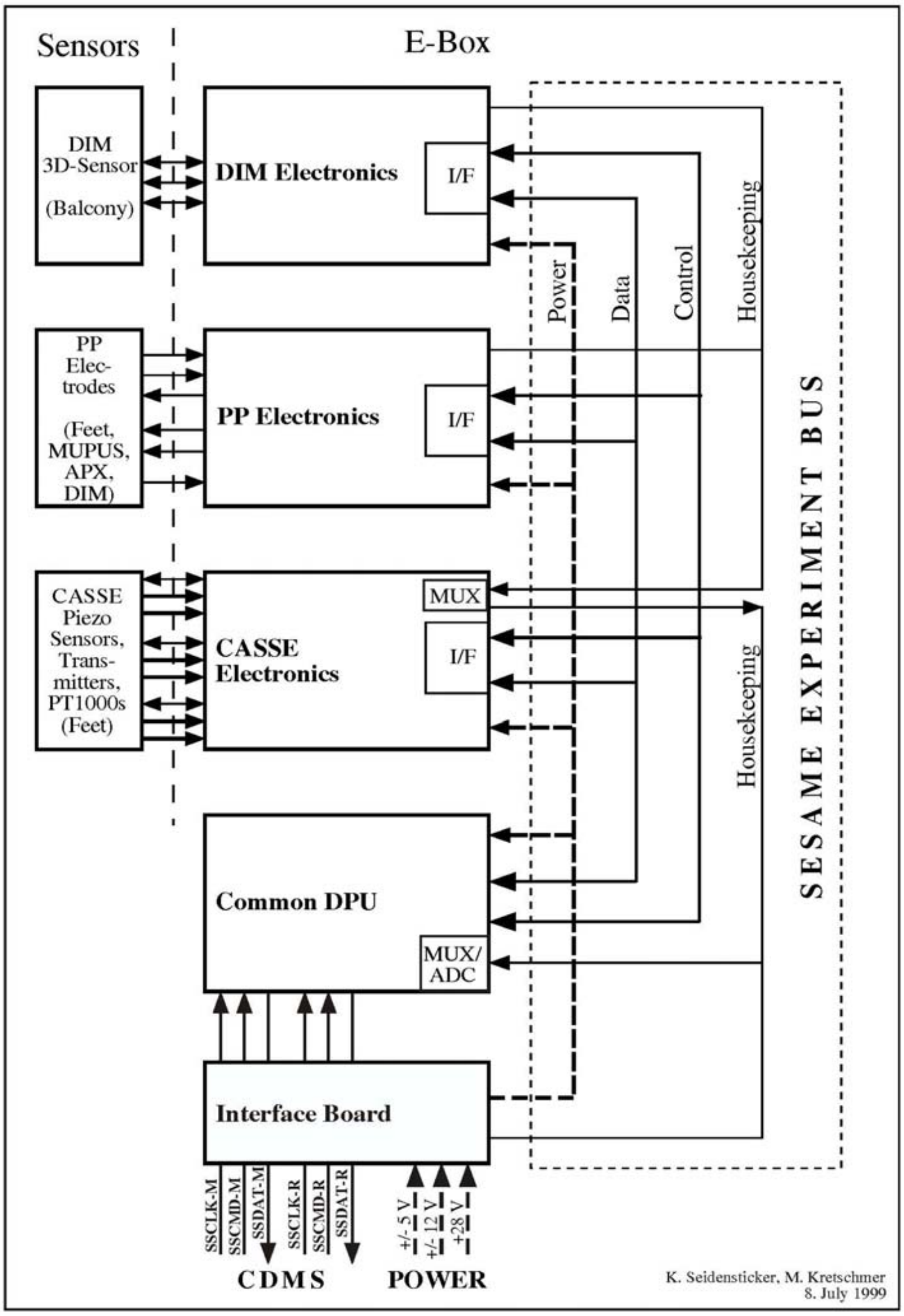

Figure 1: SESAME Block Diagram

3.1 Common Electronics

The Common Electronics includes the Common DPU board (C-DPU), the interface board (connecting the Central Electronics to the Lander CDMS bus) and an interconnecting printed circuit board (PCB) used as an internal bus, the SESAME Experiment Bus (SEB). The interface board contains power switching equipment, the CDMS interface and a small additional board with HK acquisition and latchup protection circuitry. A detailed description of these components can be found in the SESAME E-Box Specification (RO-LSE-SP-3802).

Common DPU
The C-DPU is a universal processor board designed for the Rosetta Lander; dedicated versions of this board are used for the experiments CIVA/ROLIS, COSAC, MUPUS, SESAME and SD2. See figure 2 for a block diagram of the Common DPU.

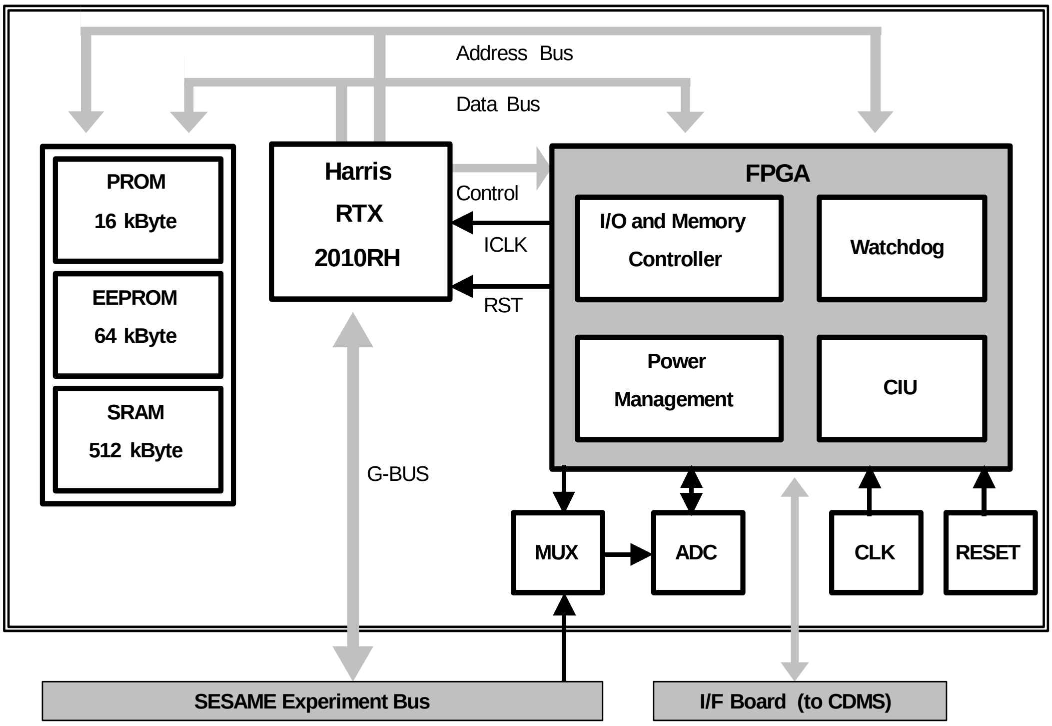

Figure 2: Block Diagram of the SESAME C-DPU Board

The C-DPU is equipped with the radiation hardened RTX2010 processor (Harris corporation), which is a 16-bit microcontroller with a stack oriented multiple bus architecture. The adjusted processor instruction frequency is 5 MHz. External data is transferred to and from the microcontroller via the 16-bit memory data bus and the 16-bit ASIC bus. The memory bus addresses 16 pages with 64 KByte each, which compose the one Megabyte of memory bus address space. The ASIC bus addresses eight external locations and is used for communication with the instrument PCBs ("G-BUS").

Memory components on the C-DPU are a 16 KByte PROM, an EEPROM (64 KByte) and static RAM. The PROM contains the Common DPU software kernel, called the C-DPU Debug Monitor. Upon a system reset the PROM contents is copied to static RAM and executed. The SESAME flight software is stored in the EEPROM, its booting is initiated by the Debug Monitor. To this end the flight S/W is copied to the first page of the SRAM ("Code Page") and executed. The SESAME version of the C-DPU contains two 512 KByte SRAM modules, but only a total of 512 KByte can be addressed, because memory bus addresses above 512 KByte are used to access external hardware. Therefore up to 64 KByte can be used for the SESAME program code and data on the first SRAM page and another 7 pages (64 KByte each) for data.

The C-DPU is equipped with a 14-bit A/D converter and a 16-channel multiplexer. One channel is reserved for the measurement of the C-DPU supply voltage on the +5 V line, thus 15 channels are available for A/D conversion of SESAME specific analogue values.

The hardware interface to the CDMS is implemented in the FPGA (in figure 2 marked as "CIU", i.e. Central Interface Unit). If SESAME is addressed by the CDMS an interrupt is generated, and the interrupt vector is set according to the contents of the CDMS message.

Deviating from the statement in the C-DPU User Manual (RO-LCO-PR-3304), a low power mode (with a reduced clock frequency) is not possible. The low power mode has been disabled via hardware means on the SESAME C-DPU board because switching between low and normal power mode might cause malfunction (C-DPU bug #3, mail by R. Schrödter, 15. Jan. 2001).

Further details on the C-DPU H/W can be found in the C-DPU User Manual. A comprehensive description of the processor architecture and its programming is contained in the HS-RTX2010RH data sheet and the Programmer's Reference Manual.

3.2 CASSE Instrument

The CASSE instrument consists of a PCB connected to the SEB in the E-Box and transmitters and sensors (accelerometers and temperature sensors) in the Philae soles. The PCB contains a 12-channel transient recorder with a programmable sampling rate up to 100 kHz and a 3-channel frequency generator. Incoming sensor signals are selected by an analogue multiplexer and after amplification converted using an 8-bit ADC (with integrated flattening of the A/D characteristic curve to extend the dynamic measuring range). Measured data are written to the data acquisition RAM, where up to 128 KByte can be stored. It is possible to select any combination of twelve sensor channels (which can be the x, y, and z axes of each accelerometer and the three transmitters) by an appropriate setting of the sensor lookup table (SLT). During data acquisition the sensor channel is switched to the next channel in the SLT after each sample, thus the sampling data flux is distributed among the adjusted channels. An event detection unit on the CASSE PCB can be used to indicate that measuring data exceed programmable trigger thresholds. The transmitter frequency is derived from the sampling frequency by a programmable frequency divider. Any combination of transmitters can be selected to emit a rectangular shaped oscillation.

An 8-channel multiplexer on the CASSE PCB is used to select some of the analogue SESAME housekeeping and science data. The conversion to digital values takes place via the ADC of the C-DPU. To this end, the output of the CASSE multiplexer is connected to the INR14 input channel of the C-DPU multiplexer. Data measured this way include all DIM analogue measured values and the CASSE PT1000 measurements (temperature sensors at the feet and at the CASSE PCB may be selected separately by CASSE register setting). Additionally the offset voltage of a **Rad**iation-sensitive **F**ield-**E**ffect **T**ransistor (RadFET) mounted on the CASSE PCB can be selected for the measurement of a total ionizing dose signal.

ASIC bus address 26 is assigned to the CASSE status and control register, and bus address 27 to the CASSE address register. More details can be found in the CASSE PCB User Guide (RO-LSE-UG-3821).

3.3 DIM Instrument

DIM is composed of a PCB in the E-Box and a cube-shaped sensor, which is located above the "balcony" at the upper part of Philae. The sensor has sensing faces looking into three orthogonal directions (DIM coordinates x, y, z), each assembled of three piezoelectric segments. Each direction is connected to the electronics using a shielded cable. The data acquisition unit includes input selector switches (x, y, z), a preamplifier, a logarithmic-amplifier, peak detector, average and impact-time measuring circuits, threshold circuit, bus-transceivers, power-down circuits and an over-current circuit. Besides its main (passive) measuring mode, which registers dust impacts on the sensor, DIM sensor segments will be actively excited by applying electric pulses for calibration purposes.

The DIM PCB does not contain an A/D converter nor a multiplexer, thus all DIM analogue data have to be converted using the C-DPU ADC (via the CASSE and C-DPU multiplexers). In case of over-current at either supply line the DIM over-current circuit generates an interrupt (RTX external interrupt 4 - EI4). DIM power supply may be switched by software using the DIM select line (cf. RO-LSE-SP-3802).

ASIC bus address 28 is assigned to the DIM index register, and bus address 29 to the DIM data address register.

3.4 PP Instrument

PP consists of the PP PCB in the E-Box and transmitting electrodes and active receivers at the Lander feet and at the sensor assemblies of APX and MUPUS. Additionally an electrode for Langmuir Probe measurements is fixed at the DIM sensor on Philae's "balcony".

The transmitter part of the PP PCB has three electrode drivers including current measurement circuits, an 8-bit DAC for the generation of the sinusoidal signal, and a switch set to select two out of the three transmitting electrodes. The receiver electronics includes two sensor amplifiers, an analogue multiplexer and an ADC. Transceiver current and receiver voltage samples are stored into a 32 KByte RAM on board. The electronics for Langmuir Probe-like measurements includes a preamplifier, an integrator and reset logic.

ASIC bus address 24 is assigned to the PP control and status register, and bus address 25 is used for PP register and memory access.

4 Software Description

4.1 General

It should be emphasized once again that **two different software programs** (the C-DPU Debug Monitor and the SESAME flight software) run on the C-DPU during different operational phases of SESAME. Each has its specific telecommand processing (and does not understand telecommands addressed to the other program) and delivers different housekeeping parameters. After power-on the C-DPU Debug Monitor is booted from PROM. This program is almost identical for all experiments which use the Common DPU. Its features are described in the C-DPU User Manual. Upon a specific telecommand to the Debug Monitor or automatically, if no telecommand is received within one minute after power-on, SESAME flight software is booted. The following chapters describe the SESAME flight software only. Further details may be found in the software code, which has been commented in detail. Special features of the current software release are listed in the software release notes.

Programming language is Forth-83 (cf. LMI UR-FORTH manual). The Forth language corresponds best to the processor's specific architecture and allows the programming of small and fast code. Starting with flight software version FM-2, we use the LMI meta-compiler version 4.2. In contrast to version 3.0 (used for FM-1) it supports ASCII/text source files and compiles them to the RTX target (cf. email by Rolf Schrödter [DLR-BA, 6. February 2006] and LMI metacompiler manual [for version 3.0]). The programming environment and Forth itself give little assistance to the developer in avoiding programming errors. Therefore careful programming and intensive testing is necessary. The implementation status of user requirements for a particular software version and the tests performed are described in the software release notes for that version.

Software development follows the guidelines defined in the software quality assurance document (RO-LSE-PL-3401). An iterative incremental model has been applied because user requirements have been specified with increasing precision during software development.

Basic software user requirements have been collected and are listed in RO-LSE-RD-3401. More detailed information on instrument-specific requirements and operational aspects is given in the software specifications of CASSE (RO-LSE-SP-3420), DIM (RO-LSE-SP-3440) and PP (RO-LSE-SP-3460). DIM and PP specifications are additionally clarified in “Clarification of DIM Software User Requirements – Addendum to RO-LSE-SP-3440” and “PP Basic Algorithms and Software Test”. The definitions laid down in the latter two documents supersede the original specification documents.

4.2 Overview of Functional Software Groups

See figure 3 for an overview of the functional groups of SESAME flight software. Data flow between SESAME and the ground station takes place via the central computer on Philae, the Command and Data Management System (CDMS), which in turn communicates with earth via the Orbiter. Along with the hardware interface the software interface to CDMS is responsible for observing the communication protocol between CDMS and SESAME. Incoming telecommands are decoded and are used to control the main task of the flight software, namely the execution of measurements of the instruments CASSE, DIM and PP. The software code for measurement control, data evaluation and formatting of science data is the central part of the flight software. Additional telecommands are used to perform non-instrument specific actions and to control the TC processing itself. SESAME software retrieves Lander and environmental status information from CDMS; on the other hand it delivers SESAME status information to CDMS. Apart from low level information concerning the communication status between SESAME and the CDMS, SESAME software actively measures or acquires a set of housekeeping parameters, which allow checking the health status of SESAME electronics. Communication with other Lander units may be achieved by the passing of trigger words or via the Backup RAM Buffer in the CDMS memory. The preferred way is writing to the own section in the Backup RAM Buffer and reading of the sections of other units.

The functionality of SESAME flight software is achieved by the program flow of the software loop and several interrupt service routines.

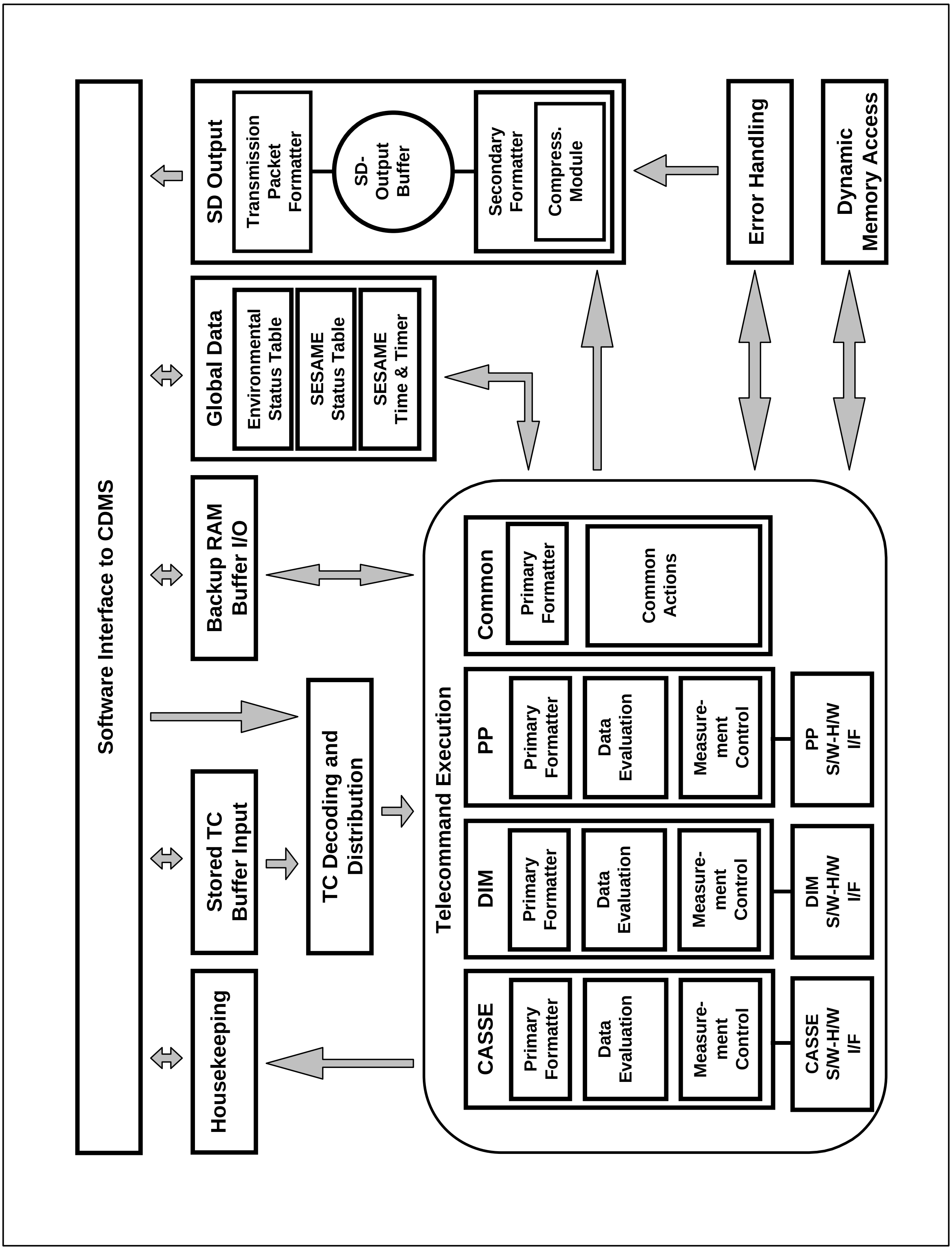

Figure 3: SESAME Flight Software: Main Functional Groups and Data Flow

4.3 Main Loop and Interrupt Sources

The main loop of the flight software is depicted in figure 4. After some initialization it is checked if a telecommand (TC) arrived. If yes, the TC is passed to dedicated software modules for further processing. Telecommand processing is skipped, if it is disabled (TC processing can be disabled by TC for a certain period of time or until a certain Lander Onboard Time).

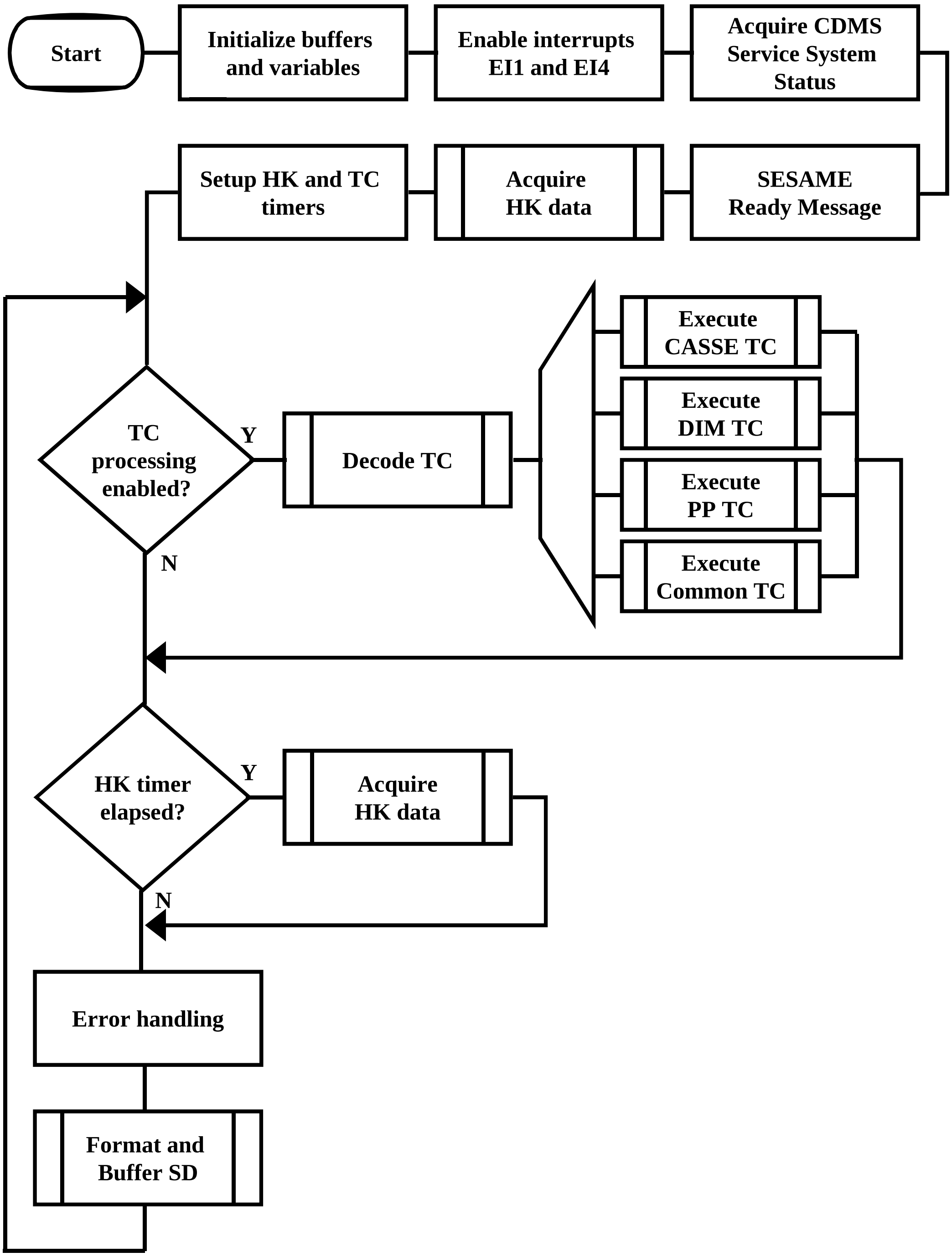

Figure 4: Main Software Loop

Likewise, the acquisition of HK values is conditionally executed, depending on the actual transmission status of HK parameters to CDMS. The software loop is completed by a global error check and the preparation of generated science data (SD) for sending to CDMS. Due to the rigid timing requirements of the CDMS communication protocol the actual reception and sending of data does not take place within the main program flow, but it is carried out by interrupt routines. Some other interrupts need to be treated as well. Table 1 contains a list of interrupt sources, which are recognized and evaluated by SESAME flight software. Together with the main program code the corresponding interrupt routines are described in the following chapters.

Table 1: Recognized Interrupt Sources

Interrupt Source (*)		**Used for...**	**Cf. Chapter...**
EI1	External Interrupt 1	CDMS Interface	"Interface to the CDMS"
EI2	External Interrupt 2	ADC	"Housekeeping and ADC"
EI4	External Interrupt 4	CASSE (**), DIM S/W	"DIM Operation"
TCI0	RTX Timer 0	Time, Timing	"Time and Timers"
TCI1	RTX Timer 1		
TCI2	RTX Timer 2		

(*) notation according to the RTX User Manual
(**) The CASSE trigger unit is a potential EI4 source, but signalling of an event via EI4 has never been enabled. Instead polling of the trigger status registers is used for event detection.

4.4 Interface to CDMS

The software interface to CDMS comprises two layers: the low-level layer ("transport layer"), consisting of interrupt service routines, fulfils along with the H/W interface the communication protocol laid down in the CDMS subsystem specification. A second layer ("application layer") provides routines for the data exchange with the CDMS which can be used without bothering with communication details.

The **application layer** routines are listed in table 2. The routines work non-blocking, i.e. a data transfer is initiated, but it is generally not completed when the routine returns. In worst case CDMS is occupied with high priority tasks (like telecommand reception from and science data transfer to the Orbiter), when SESAME sends a request for data exchange. In this case a request processing can take approx. 35 seconds (private communication with CDMS developer team) or CDMS may send a "Request Undue" error to SESAME along with a CDMS Receive Error Code Word (RERC) message. If the completion of data transfer is required for further processing, after a call of a transfer routine a loop with an appropriate timeout should be included, which repetitively checks whether an error occurred (using **`GetCDMSErc (-- n)`**) and if the transfer has been completed or not by checking the status word of the data transfer in question (cf. table 2).

The FORTH routines for the reading of Backup RAM Buffer and Stored TC Buffer store the received data to a user selectable location in SESAME SRAM. Care must be taken not to overwrite science data stored in SRAM (e.g. by using destination addresses allocated statically on page 0 during compilation).

Main tasks of the SESAME software interface to the CDMS are the buffering of incoming data (e.g. TC and Backup RAM Buffer records), the sending of data (e.g. science data, HK) in appropriate amounts (words, records), and the correct setting of the SESAME Status Word. The **transport layer** is based on the Common DPU BIOS (cf. the C-DPU user manual). The BIOS is configured with **`CE/ME?`** compiler option on, i.e. the handling of the **Count Error (CE) flag** and the **Message Error (ME) flag** in the Status Word is enabled. The Count Error flag is set by the C-DPU BIOS, whenever the number of command words is different from the WRDC (word count) value in the Subsystem Address Word. The ME flag is set by the SESAME Flight S/W, whenever it encounters an invalid Action Code (ACTC) in the Subsystem Address Word. An Action Code is regarded invalid, if ACTC > 15.

SESAME software provides three callback routines (**`msgSTAT`**, **`msgCMD`** and **`msgDATA)`**, which are invoked by the BIOS upon CDMS status, command, broadcast and data messages (command and broadcast messages are handled by the same callback routine). The maximum execution time of a callback is determined by the transmission time of the Status Word, which is approx. 0.5 ms. Each callback is provided with at least one input parameter, the CDMS Subsystem Address Word. It is used to retrieve the subunit address, the Action Code of the message and **`WRDC`**, the number of words to receive or send. See table 3 for a list of all CDMS Action Codes and their handling by SESAME software.

The callback **`msgSTAT`** is invoked by the BIOS, if the Action Code of an incoming CDMS message is zero. If application layer routines have submitted a request (see table 4 for all applicable Request Codes) the callback sets the Service Request Flag in the Status Word, which will be submitted to the CDMS upon the next CDMS status request. The routine **`msgCMD`** is called, if the Action Code is non-zero, and the T/R-Bit in the SSADR word is not set. Depending on the Action Code, command words coming along with the CDMS message are distributed to different locations in SESAME RAM: the telecommand buffer, status table... Upon a non-zero Action Code, with T/R-bit set in SSADR, the callback **`msgDATA`** is invoked. Depending on the Action Code the callback delivers an address in SESAME SRAM, where e.g. a HK value, a science data record etc. can be found.

Table 2: CDMS I/F: Application Layer Routines	
AddRequest (rqc -- erc)	Submits a request to CDMS (see table 3 for valid Request Code names **rqc**).
GetAMDTId (-- n)	Returns ID of AMDT according to last RMOD message.
GetCDMSErc (-- n)	Returns the CDMS Error Code Word, which is delivered by CDMS if a SESAME request could not be served. The meaning of the Error Code Word is described in the CDMS Subsystem Specification.
GetCDMSMode (-- n)	Returns CDMS mode according to last RMOD message.
GetSSCLKFreq (-- n)	Returns SSCLK frequency according to last RMOD message.
NewCDMSmsg? (actc -- ?)	Returns **TRUE**, if a CDMS message with action code **actc** has arrived since last call of **NewCDMSmsg?,** else **FALSE.** See table 3 for valid Action Code names.
RdBB (suadr nstart cnt pg adr -- erc)	Reads **cnt** records from the Backup RAM Buffer of unit **suadr** starting with record **nstart** and store to SESAME RAM starting at (page=**pg**, address=**adr**).
RdStoredTC (of len adr pg -- erc)	Reads **len** words from Stored TC buffer starting at offset **of** and store to SESAME RAM at (page=**pg**, address=**adr**).
WrBB (pg adr nstart cnt -- erc)	Writes **cnt** data records from SESAME RAM starting at (page=**pg**, address=**adr**) to SESAME Backup RAM Buffer (starting with record **nstart**).
WrTRG (n suadr -- erc)	Sends trigger word **n** to unit **suadr.** Valid subunit addresses are defined in the CDMS Subsystem Specification.
Access to Transfer Status Words Possible values of Status Words: **IO_WAIT** (transfer not yet completed) or **IO_DONE** (transfer completed)	
IOC +IOC.BB +BB.STAT @	Status word for Backup RAM Buffer data transfer
IOC +IOC.STC +STC.STAT @	Status word for Stored TC Buffer data transfer
IOC +IOC.TRG.STAT @	Status word for passing of a trigger word

Table 3: Recognised CDMS Action Codes

Action Code (name in flight S/W)	Short description	Implemented / not implemented	Implemented but not used
Transmit status word (**ACTC_TRSW**)	In status word, ME or CE flag are set upon error. SR flag is set upon request, BSY is never set.	Implemented	
Transmit request code word (**ACTC_TRQC**)	Fetch next request code word from SESAME request word queue and submits to CDMS.	Implemented	
Stand-by/power down mode (**ACTC_STBY**)		Not implemented	
Receive current CDMS mode (**ACTC_RMOD**)	Store mode, frequency and AMDT id. in SESAME RAM.		In future decisions may possibly depend on SSCLK frequency.
Receive service system status (**ACTC_RSST**)	Store System Status in SESAME SRAM.	Implemented	
Receive action code/sub-address extension (**ACTC_RAXT**)		Not implemented	
Receive housekeeping data format count (**ACTC_RHFM**)	Prepare HK word	Implemented	
Transmit housekeeping data word (**ACTC_THKD**)	Submit HK word	Implemented	
Receive telecommand sequence (**ACTC_RCMD**)	TC decoding /verification	Implemented	
Transmit offset/length of stored telecommand buffer section (**ACTC_TCMO**)	Used for CASSE jobcards.	Implemented	
Receive stored telecommand buffer section (**ACTC_RCMS**)	Used for CASSE jobcards.	Implemented	
Receive allocated science data volume (**ACTC_RASV**)			In future: SD transfer procedure may depend on ASV.

Table 3: Recognised CDMS Action Codes

Action Code (name in flight S/W)	Short description	Implemented / not implemented	Implemented but not used
Transmit science data burst (**ACTC_TSCR**)		Implemented	
Receive science data packet checksum (**ACTC_RSCS**)	SCS is compared with own checksum; next SD packet header depends on the result of the comparison.	Implemented	
Receive allocated Backup RAM Buffer size (**ACTC_RBUS**)			Possibly used in future releases.
Transmit pointer of Backup RAM record (ACTC_TBUP)	Used for communication with other instruments	Implemented	
Transmit Backup RAM record (**ACTC_TBUF**)			In future releases possibly used for temporary storage of data.
Receive Backup RAM record (**ACTC_RBUF**)	Used for communication with other instruments	Implemented	
Transmit trigger word (**ACTC_TTRG**)			In future releases possibly used for communication with other instruments.
Receive trigger word (**ACTC_RTRG**)			In future releases possibly used for communication with other instruments.
Receive error code word (**ACTC_RERC**)	Note error in HK parameter ERRF; further action depends on error code.	Implemented	

Table 4: Applicable Request Codes		
Request code (name in SESAME flight S/W)	**Short description**	**Implemented / not implemented**
Send service system status (**RQC_SSST**)		Implemented.
Send stored telecommand buffer section (**RQC_SCMD**)	Used for reading CASSE jobcards in STC buffer.	Implemented.
Send allocated science data volume (**RQC_SASV**)		Not implemented; Will possibly be implemented in future releases.
Science data ready (**RQC_SRDY**)	Used for SD and special messages.	Implemented.
Send allocated Backup RAM buffer size (**RQC_SBUS**)		Not implemented; Will possibly be implemented in future releases.
Write Backup RAM record (**RQC_WRBF**)		Implemented, but not used; will possibly be used in future releases.
Read Backup RAM record (**RQC_RDBF**)	Used for communication with other instruments.	Implemented.
Pass trigger word (**RQC_PTRG**)		Implemented, but not used.
Flush last science data packet (**RQC_FLSP**)		Implemented, but not used.

4.5 Telecommand Processing

Telecommands may be delivered by the CDMS to SESAME without request of SESAME („direct telecommands“), or the CDMS delivers a portion of the Stored TC Buffer upon request of SESAME flight software („indirect telecommands“). Direct telecommands are received by the CDMS interface and stored in a telecommand buffer. This buffer is examined in the main program. Within each software loop one telecommand is processed (as long as there are commands in the telecommand queue and TC processing is not disabled) and the corresponding action is initiated (figure 5). Flight S/W does not autonomously acquire sections of its Stored Telecommand Buffer in the CDMS memory. However, it may be commanded to read a record from the Stored TC Buffer in order to demonstrate that indirect commanding from Stored TC buffer works.

```
: ProcessTC ( --)
   TCIN \ any unprocessed TC?   ( cmd par #par t | f)
   IF ROT DUP @ MA_TCCAT AND    ( par #par cmd cat)
      LAST_TC @ LAST_TC2 !   \ save last command executed
      OVER @ LAST_TC !       \ save command being executed
      CASE                   \ distribute command
         1000 OF doCASSECommand ENDOF
         3000 OF doDIMCommand   ENDOF
         5000 OF doPPCommand    ENDOF
         6000 OF doPPCommand    ENDOF
         7000 OF doCDPUCommand  ENDOF
         3DROP 1601 ERRMSG  \ invalid command category
      ENDCASE
   THEN
;
```

Figure 5: Command Decoding and Distribution

4.5.1 Format of a Telecommand

Each telecommand consists of a command word and up to 31 parameter words. A command word has the following bit structure:

Command Word Bit Structure															
15	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
Category				**Action Code**				***free***			**Parameter Word Count PCT**				

Category:

0x0	reserved
0x1	CASSE instrument control
0x2	CASSE instrument control (spare)
0x3	DIM instrument control
0x4	DIM instrument control (spare)
0x5	PP instrument control
0x6	PP instrument control
0x7	Common actions (0x7Fxx not used)
0x8	Common actions (spare)
0xD	not used (to avoid the danger of user's mix-up with 0xDEBx commands)

Action Code: up to 15 actions per category

PCT: number of parameter words

The number of parameter words following a command word must be equal to the parameter count in the parameter count (PCT) field of the command word.

Command Records

Several commands can be combined to a command record with up to 32 words. No gaps are allowed between commands; a command must be completely contained in one record.

A comprehensive description of the defined telecommands is contained in the chapter "Telecommands and expected Science Data Output".

4.6 Operation of Instruments

The present chapter contains a short description of the operation of instruments and the corresponding software control. More comprehensive information shall be given in dedicated instruments user manuals. A (currently somewhat obsolete) compilation of operation modes of the SESAME instruments CASSE, DIM, and PP is given in the SESAME Operations Plan (RO-LSE-PL-3102).

4.6.1 CASSE Operation

4.6.1.1 CASSE Operation Modes

CASSE operation is controlled using a set of measurement parameters, which are compiled in a structure called jobcard. The jobcard is usually sent to the flight software using a single telecommand. A second TC is used to start the execution of the jobcard. Flight software evaluates the jobcard and invokes one of four main operation modes, namely *listening*, *triggered*, *sounding*, and *health-check* mode.

Common features of all CASSE operation modes are:

- For data acquisition, an arbitrary subset of the twelve sensor channels can be selected. The channels consist of the x, y, and z-axes of the three piezoelectric accelerometers, each located in one sole of the Philae feet, and of the three Piezo transmitters, which are mounted in the other sole of each foot. Care must be taken when combining accelerometer and transmitter channels, because due to different electrical properties of the sensors and the electronics input circuits the measuring range can easily be exceeded.
- The output signals of the sensors channels are intermittently (“quasi parallel”) read out with an overall sampling rate of up to 100 kHz. The maximum length of a time series is 6553.5 ms (restricted by the format of the corresponding jobcard parameter).
- Each CASSE measurement sequence is preceded by an accelerometer (ACC) sensor “warm-up” period (one minute). During that period the three accelerometers are fully powered to achieve a steady state of the ACC preamplifiers. Additionally, prior to each measurement a blind measurement (without data read-out) with the same instrument adjustments is executed, which lasts five seconds. During that “amplifier setup period” constant signal offsets are tuned in.
- After it stopped the measurement, SESAME flight software takes the recorded raw data, groups the interleaved sample data into time series of the single channels and converts the CASSE internal number format to the common number format. Along with meta-data the time series are fed into the science data stream.

During **CASSE Listening Mode** none of the transmitters is emitting an acoustic signal. The Listening Mode is used for observing external natural (e.g. comet quakes, particle impacts) or artificial sources (e.g. MUPUS hammering) and it can also determine an elevated background caused by interference (e.g. vibration caused by the reaction wheels during cruise or by the Philae flywheel during descent).

In **CASSE Sounding Mode** up to three transmitters can be activated simultaneously to emit short rectangular shaped signals ("pings") with frequencies in the range 100 Hz to a few kHz. The range of adjustable sound frequencies is related to the sampling frequency per channel. See the CASSE User Guide (RO-LSE-UG-3821) for the applicable equations. The Sounding Mode is primarily used to determine the velocities of elastic waves between the Lander feet. More elaborated operations are under consideration, which could possibly examine a layered structure beneath Philae. This might require a time-shifted operation of the transmitters, which is currently not possible.

The **CASSE Triggered Mode** is a variant of the listening mode: After the start of the signal recording CASSE RAM is filled in FIFO mode (i.e. sample storage addresses wrap around at 128 KByte). The trigger unit on the CASSE PCB indicates, whether programmable trigger thresholds were exceeded by the signals on the selected sensor channels. When such an event is recognised flight software stops the measurement (optionally after an adjustable delay) and the time series of a specified time interval before and after the event are read out.

Deviating from the other operation modes, for which the measuring duration is adjusted such that not more than 128 KByte sample data are recorded, in Triggered Mode the CASSE FIFO RAM can be filled up several times. Therefore the assignment of time series to physical sensor channels can not always be easily derived from the Sensor-Lookup-Table. In case the number of sensor channels is not a power of two (1, 2, 4, 8), the addresses of each channel in CASSE RAM are shifted with each wrap-around at 128 KByte. For a later assignment of data to channels (on ground) the information is needed, how often CASSE RAM was filled before the measurement was stopped. To this end telemetry of CASSE Triggered Mode contains information on CASSE RAM addresses and time stamps for particular points in time during the measurement. The algorithm for the evaluation of this additional information was already implemented in SESAME ground software AliBaba (starting with AliBaba version 1.4.1).

Additionally a **CASSE Health Check** is implemented. The objective of this operation mode is to provide the values of a standardized measuring sequence giving information on the health status of the CASSE PCB, sensors and transmitters. The health check is a CASSE sounding measurement with all instrument settings fixed in the software code.

The final CASSE operating concept will include more autonomous measurements on comet (e.g. automatic adjustment of gain or trigger levels) and will probably additionally consider CASSE operations, which are tailored to particular measuring objectives (e.g. synchronised listening to MUPUS PEN activity).

4.6.1.2 Commanding and Software Control

The description of the applicable instrument and measurement settings for all CASSE operation modes has been unified by introducing the jobcard concept. According to the CASSE software specification each measurement is controlled using a 32 byte structure (called jobcard), which contains 21 parameters. Parameters include nominal values of CASSE PCB register settings, which are written to the registers by flight software without conversion (e.g. the amplifier gain) and magnitudes (e.g. the sampling frequency), which require an onboard calculation of the appropriate register settings. Other entries in a jobcard describe the desired temporal course of a sequence of measurements and the timing of an individual measurement. The setting and the combination of jobcard parameters determine the kind of measurement and thus each CASSE measurement is initiated by flight software after the jobcard has been analyzed.

The main difference between health check and all other CASSE measurements is, that the controlling jobcard for the health check is fixed in the EEPROM (jobcard **JOB_HC**), and can only be updated with a software patch and not by a regular telecommand. A default jobcard (**JOB_MES**) for all other measurements is contained in the S/W code; it may be temporarily overwritten by telecommand (**CAS_RJC).** An alternative way of CASSE commanding is the reading of jobcards from Stored TC Buffer (this is demonstrated by telecommand **COM_RDJC**). Apart from TCs for the control of measurements flight software recognizes telecommands for the power control of the CASSE PCB and a special debug command, which is used during software and hardware testing only. The currently implemented commands are described in the chapter "Telecommands and Expected Science Data Output".

After the analysis of the jobcard, all CASSE operations modes but the Triggered Mode are carried out by the same main software routine. The special treatment of the Triggered Mode is not only due to the fact, that it has been added later, but also because a more complex timing and memory access has to be performed than during the other modes. Consequently, the telemetry format of the triggered mode differs from that of all other modes. Additional information (time stamps, memory addresses) is included in the TM to allow the identification of the single sensor channels and to determine the exact trigger event time on ground.

4.6.2 DIM Operation

4.6.2.1 Operation Modes

When the DIM instrument is measuring, there will be 2 operation modes that are activa-ted by a supervising routine, depending on the impact rate of particles observed at the piezoelectric plates for the x-, y- and z-direction: **DIM Burst** (Single Event) **Continuous Mode** and **DIM Average Continuous Mode**.

DIM Burst Continuous Mode is the default option for medium to low particle impact rates, when the signals of the impact events are basically non-overlapping in time. The objective is to gather information on single impact events. An event is defined by an adjustable threshold for the output signal of the piezoelectric plate segments.

Peak Amplitude and *Half Contact Time* are registered for each event, whereas the *Signal Average* is determined periodically at a lower sampling rate. The samples of the Signal Average will be equally spaced over the whole measuring time.

At higher dust impact rates, when single impacts are no longer distinguishable, the DIM measuring process will be switched to **DIM Average Continuous Mode**. In this mode only the signal average will be collected.

The objective of **DIM Health Check** is to provide a set of parameters that are indicative of the health status of DIM and that are measured independent of the CDMS housekeeping collecting cycle. The DIM Health Check mode consists of several subroutines that perform dedicated tests of the various DIM functions, e.g. control of supply voltages, calibration and test of sensor.

The main DIM operation modes mentioned above can be individually invoked by single telecommands or they can be executed depending on the dust environment and the status of sensor faces using the **DIM Autonomous Mode**. In Autonomous Mode, depending on the results of an initial health check, intact sensor faces are selected and Burst Continuous or Average Continuous Mode measurements are chosen. The impact detection threshold (margin) is selected according to the result of the Noise Test (part of DIM HC) and possibly corrected after a pre-Burst Continuous measurement, which is used to compare the number of accepted events, long events and false events.

4.6.2.2 Commanding and Software Control

A set of software modules was implemented, which perform particular DIM test and calibration measurements: **`DIMCheckPower`**, **`DIMNoiseTest`**, **`DIMCalibration`**, **`DIMSensorTest`**. These modules are consecutively executed during a DIM health check or may be individually invoked by telecommand. The software modules for burst and continuous mode dust impact measurements come in two versions, which differ in the format and amount of output data generated.

After DIM Autonomous Mode is commanded an initial DIM health check is performed. A decision module determines which of the sensor faces shall be used for Burst Continuous or Average Continuous measurements. The measurement sequence is completed with a final DIM health check.

All DIM telecommands are listed in the chapter "Telecommands and Expected Science Data Output".

If currents on +5V or -5V line exceed certain limits an EI4 interrupt is released, caused by the overcurrent sensing circuit on DIM PCB. According to the DIM software specification flight software should immediately switch off DIM in case an overcurrent event is detected. However, we know from experience that sometimes overcurrent signals occur (particularly when DIM is switched on), which do not indicate a harmful situation. Therefore the “switch-off on overcurrent” feature was never activated with flight software FM-1. To provide a certain degree of safety for DIM electronics, flight software FM-2 switches DIM off in case a permanent overcurrent is indicated. To this end, an interrupt routine **`isr$int4`** counts the number of EI4 interrupts and, in case the number exceeds ten per DIM procedure, it interrupts DIM voltage supply. The EI4 counter is cleared 50 ms after DIM is switched on and if DIM is switched off in a procedure. Both events, the occurrence of an EI4 interrupt and the switch off due to excessive interrupts, are indicated in the error code of a DIM procedure.

4.6.3 PP Operation

The PP instrument has three main operation modes utilising 5 sensors (3 transmitting electrodes [at Philae foot +X, MUPUS-PEN and APX] and 2 receiving active sensors [at Philae feet –Y and +Y]) and one Langmuir Probe (receiving sensor). Main measuring parameters are voltages and currents observed between 2 of the 5 sensors or currents received by the Langmuir Probe.

In **PP Passive Mode**, the potential difference (voltage) between the two receiving sensors is measured with a fixed sampling rate (default 40 kHz) for a short time interval (default: approximately 205 ms). This data set is then analysed by SESAME flight software with respect to the power distributed across 20 frequency bands, using a simplified wavelet approach for the conversion between time and frequency domain.

In **PP Active Mode**, two electrodes out of three transmitter electrodes are selected to inject an electrical current produced by a controllable AC-voltage source. Any current frequency between 20 Hz and 10 kHz can be selected. Since the injected signal is generated via a table-controlled Digital-to-Analogue-Converter (DAC) with subsequent low-pass filtering, a wide variety of voltage levels or waveforms can be created. However, only sinusoidal waveforms with three adjustable voltage levels are used. The current induces a potential field in the landing site material that is probed with the two receiving electrodes. Both, the injected current and the resulting potential difference are sampled simultaneously (on the same clock signal edge) with a sampling rate high enough to give a 0.5 degree phase difference resolution between the two signals.

An active measurement consists of (i) current injection, (ii) current and voltage sampling, and (iii) subsequent off-line analysis by SESAME flight software. These steps are repeated for 20 transmitting frequencies between 20 Hz and 10 kHz. For each of the 20 frequencies the analysis yields the results: averaged peak current, averaged peak voltage, phase difference and additional information on the data range of current and voltage time series.

The electrical current measured by the **Langmuir Probe** (receiving sensor) will be utilised to record the ambient electron flux and to determine the respective electron density. The sampling duration per value will be <1 s, typically less than 1 ms, and the sampling rate is chosen to be one measurement every 64 s (during regular housekeeping). The data width of one Langmuir measurement is 16 bit.

The objective of the **PP Health Check** is to provide a measurement of PP health check parameters that is independent of the CDMS housekeeping collecting cycle.

Besides the regular active and passive modes test versions are provided, which include the raw data of the time series along with the results of the onboard evaluation. This enables a more detailed analysis of data on ground (in particular cases) and provides a means for checking the onboard evaluation.

Almost all measuring parameters, which define an active or passive PP mode, are defined in a structure called PP control table. This data structure is part of the flight software code and can be altered using a software patch. The content of the PP control table is listed in table 5.

A detailed description of PP operation modes and software control is contained in "PP Basic Algorithms and Software Test" (RO-LSE-TR-3460).

Table 5: Parameters in PP Control Table

Name	Meaning	Value
INTDIV	Clock divider for Langmuir Probe (LP)	15
LMREP	Repetition count for LP	*not used*
NSAMP	Number of used samples for Passive Mode (excluding skipped samples)	8192
SFREQ	Sampling frequency [Hz] for Passive Mode	40000
NSKIP	Number of skipped samples for Passive Mode	512
NBIN	Number of frequency bins for onboard evaluation of Passive Mode data	10
NFREQ	Number of transmitting frequencies for Active Mode	20
freq00 to freq19	20 transmitting frequencies [Hz] for Active Mode	20, 60, 140, 280, 400, 600, 800, 1000, 1200, 1400, 1800, 2000, 2400, 3000, 3500, 5000, 6000, 7000, 8500, 10000
ELEC	Electrode combination for Active Mode	*not used*

4.7 Science Data Processing

4.7.1 Overview

The data pages of SESAME SRAM are used to store the results of measurements (SD = science data) before the delivery to CDMS. There are seven data pages (pages 1 to 7) with 64 KByte each, thus the maximum amount of science data that can be stored is 448 KByte. Temporary data (e.g. intermediate results of an onboard pre-evaluation) are stored in the code page of SESAME SRAM (page 0), as long as their size does not exceed the unused space in that page (i.e. memory space not occupied by program code). Else memory space for temporary data is allocated in the data pages (from the highest available address – usually 0xFFFF in page 7 – downwards), which diminishes the available memory for storage of science data. The memory space allocated for temporary data is freed after a measurement is done (also see “Details of memory allocation” below).

Whenever a measurement is finished, SESAME flight software initiates the transfer of science data to CDMS. Several software layers are involved: in the main program loop module SDOUT is invoked, which formats a SESAME science data packet. If there are less data than required to fill an entire SD packet, the rest of the packet is normally filled with zeros. This is true if no further measurement is running during the formatting process, else the rest of the packet will be filled with the science data of that measurement. The SD packet is passed to routines of the SESAME-CDMS interface, which handle the low level communication with CDMS in conjunction with the C-DPU BIOS. Depending on CDMS mode, the science data packet is transferred to CDMS in records of 32 (normal mode) or 2 (low power mode) data words. Subsequently further science data packets are formatted by module SDOUT, as long as there are science data in SESAME SRAM.

The timely execution of a measurement initiated by a telecommand is given priority to science data transfer, thus the process of science data transfer to CDMS can be interrupted by the reception of a telecommand. In that case SESAME SRAM fills up with science data. In cases where a particular timing of measurements is not important, time periods large enough for data transfer to CDMS should be included between measurements. No science data transfer from SESAME to CDMS is initiated during measurements.

If CDMS does not accept SESAME science data (e.g. because the science data volume reserved for SESAME is exhausted or CDMS mass-memory is full), SESAME receives a CDMS message with the appropriate error code. This error condition is shown in SESAME housekeeping data. Regardless of the type of error, SESAME will permanently retry to transfer science data to CDMS by sending SRDY (Science Data Ready) requests to CDMS. In contrast to former flight software versions, software version FM-2 waits for a CDMS “Receive Science Data Checksum” message (RSCS action code) only for a fixed time period (two seconds). If this waiting period elapses without reception of a CDMS checksum message, the lack of that message is indicated in the SD packet header of the next SD packet and flight software continues to transfer science data.

The actual amount of science data waiting for transfer to CDMS is monitored in the housekeeping data as well as any error condition which occurred during SD processing.

4.7.2 Details of Memory Allocation

Memory for science data storage is allocated in the data pages of SESAME SRAM from lower to higher addresses (usually starting at address 0 in page 1 and ending at address 0xFFFF in page 7). Because science data are transferred "automatically" by a second (interrupt driven) software layer, science data are stored contiguously (not fragmented). Very early in each measurement the expected amount of science data is calculated. It is checked if enough memory is available (else the execution of the measurement is refused) and memory space is reserved (it can e.g. not be used for temporary data). **It is important, that the amount of allocated memory for science data storage is a reasonable and always upper limit of the amount of SD generated later.**

For the storage of temporary data preferentially the code page is used, because access to data in the code page is easier and much faster than accessing data in the data pages. Fixed addresses in the code page are used. Data which can not be stored in the code page are allocated in the data pages, from the highest memory address (usually address 0xFFFF in page 7) downwards. During the allocation process it is checked whether enough memory space is available (by calculating the gap between the already allocated temporary data space and the used or reserved science data space). Temporary data space, which has been allocated in this way, is word aligned. It is valid at most until the end of a measurement. It can be freed earlier, but only together with all other temporarily allocated memory space. This will avoid fragmentation of memory and the introduction of a more sophisticated memory handling (e.g. garbage collection).

4.7.3 Details of Science Data Transfer

The previous flight software version FM-1 was prepared to cope with a couple of error conditions, which can occur while communicating with the CDMS. With respect to science data transfer CDMS error messages (e.g. "request undue", "mass memory full") are noticed in the HK error flags and subsequently further attempts to deliver the science data to the CDMS are undertaken (generally each SESAME request to CDMS is repeated upon an error message). But software version FM-1 relies on the delivery of the science data checksum (RSCS message) by CDMS after a complete SD packet has been transferred. In case this message is not received by SESAME, science data transfer to CDMS stops.

Like flight software version FM-1, the new software FM-2 evaluates the CDMS RSCS message (if it is received), but the actual SD transfer process will continue after a timeout period (two seconds). One weakness of the SESAME-CDMS interface remains after introducing this modification: In case the SESAME request flag in the status word (raised e.g. in order to start the transfer of one science data record) is recognized by the CDMS and CDMS answers with the TRQC message ("transmit request code word"), the request flag is cleared by hardware. If subsequently no CDMS reaction on the request code takes place (i.e. neither the acceptance of the request by sending the appropriate message nor the refusing of the request by sending an error message), the request is lost and science data transfer again stops. Clearly, the missing CDMS reaction upon the request would be a severe CDMS error and it will probably never occur; however, in S/W version FM-2 a time-out for the final completion of a SESAME request by the CDMS (either by fulfilling the request or by sending an error message) has been implemented. After two minutes, SESAME will again raise the SRDY request (and again each second minute, as long as no reaction takes place). It can not be excluded, that this exception handling can lead to problems e.g. doubled science data records. While the error handling is usually performed by the SESAME interrupt routines of the software interface to CDMS, the last mentioned action is performed by module SDOUT (because the interrupt routines are not invoked without an action of the CDMS).

4.7.4 Science Data Compression Algorithm

A reversible (lossless) compression algorithm, similar to the ESTEC1 algorithm, was implemented in Forth and tested with simulated measuring data (cf. RO-LSE-TN-3401). It consists of a one-dimensional differential pulse-code modulation (DPCM), followed by Huffmann coding of the resulting differences. Advantages of this method are fair compression ratios over a range of probability distributions of measuring data, the moderate complexity and low memory requirements during execution.
Note: Data compression is currently not used.

4.8 Housekeeping and Analogue to Digital Conversion

The set of SESAME Housekeeping parameters comprises 32 quantities from analogue and digital sources. It is stored double-buffered in SESAME SRAM. At a point in time, one buffer contains the data set being delivered to CDMS, the other buffer is used for the storage of new measuring values. The role of the buffers is switched if (CDMS HK format count modulo 32) is zero. The 32 HK parameters are measured “simultaneously” (i.e. within less than one second).

HK parameters are measured or acquired by SESAME flight software

- two seconds after S/W boot (i.e. after SESAME Local Time has been initialised as a result of a CDMS RTIM message),
- if (CDMS HK format count modulo 32) > *fmtmeas* (currently *fmtmeas* = 1). Afterwards HK measurements are disabled until again (CDMS HK format count modulo 32) > *fmtmeas*. The time gap between the measurement of HK data and switching of the HK buffers will usually be sufficient to bridge periods of actual instruments measurements (when HK measurements are still disabled).

Due to the coupling of HK measurement time and CDMS HK format count the time period between successive HK measurements will be as high as actually necessary: 64 seconds with normal CDMS HK scanning period and correspondingly lower with lower scanning frequency. Although HK measurements are usually disabled when a measurement is running, dedicated waiting periods (during CASSE sensor warm-up and during SESAME health check) are used to maintain the HK measuring cycle.

4.8.1 Analogue Sources

Within the software code, each analogue source is unequivocally identified with a one byte analogue source identifier. The structure of the identifier is:

Analogue Source Identifier: Bit Structure							
7	6	5	4	3	2	1	0
A/D	Category		SubID				

A/D

A/D = 1 indicates analogue source.

Category

indicates the meaning of SubID:

00: channel of C-DPU multiplexer
01: channel of CASSE multiplexer; C-DPU MUX channel is 14.
11: CASSE temperature sensor number; C-DPU MUX channel is INR=14. CASSE MUX channel is ANR=4.

SubID

If Category = 00: C-DPU MUX channel number (INR = 1..16)
If Category = 01: CASSE MUX channel number (ANR = 1..8)
If Category = 11: CASSE temperature sensor number (1..7)

Each analogue-digital conversion via the ADC of the Common DPU is controlled by the routine **`StartWaitADC ( aid -- val t | f).`** It accepts an analogue source identifier, sets the appropriate MUX channels and registers (on the C-DPU and on the CASSE PCB), waits until A/D conversion is completed, and scales the output of the ADC to voltage **val** [mV]. A non-successful A/D conversion is indicated by a "false" flag.

The format of an analogue HK value, passed to CDMS upon a THKD action code, is

Analogue HK Value: Bit Structure															
15	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
0	**S**			**v**	**v**	**v**	**v**	**v**	**v**	**v**	**v**	**v**	**v**	**v**	**v**
	±	**Spare**		**Housekeeping value in [mV]**											

Bit 14 (S) set for negative (cleared for positive) ***s***ign of HK values

The voltages must be scaled to the physical units of the measured quantity by ground software. Appropriate scaling factors for SESAME FM electronics are given in table 6.

4.8.2 Digital HK Parameters

In order to allow a flexible and simple collection of all HK parameters, HK parameters from digital sources are coded in a way, which is compatible to the coding of analogue sources:

Digital HK Source Identifier: Bit Structure							
7	**6**	**5**	**4**	**3**	**2**	**1**	**0**
A/D	**Number**						

A/D
A/D = 0 indicates digital source.

Number
Unique number identifying the digital source.

A software mode identifier (id = 0x1F, HK Parameter # 16) indicates that HK data have been acquired by SESAME flight software and not by C-DPU Debug Monitor. It has the constant value 0xB5E5 (the value was 0x05E5 for software version FM-1).

4.8.3 Housekeeping Parameters and Telemetry

SESAME housekeeping parameters and the assignment to the CDMS format count are listed in table 6. The scaling of analogue parameters is given for FM hardware and applies also for Philae GRM hardware. The structure and meaning of parameters SUPS, TIBO, and ERRF is described separately in the present chapter. A description of the HK procedure with former flight software versions and a compilation of transfer functions for EQM and (older) lab electronics are compiled in the HK technical note RO-LSE-TN-3402.

Table 6: Housekeeping Parameters

CDMS Format Count	HK Name (used starting with FM-2)	previous HK Name	Meaning	Scaling / Comments
0	UFPG	CA-U1	Voltage 3.3V (FPGA)	0.002 V/mV
1	UD+5	DI-U1	Voltage +5V (DIM)	0.002 V/mV
2	UD-5	DI-U2	Voltage -5V (DIM)	0.002 V/mV
3	UP+5	PP-U1	Voltage +5V (PP)	0.002 V/mV (***)
4	U+05	CE-U1	Voltage +5V (CE)	0.01 V/mV
5	U-05	CE-U2	Voltage -5V (CE)	0.01 V/mV
6	U+12	CE-U3	Voltage +12V (CE)	0.01 V/mV
7	U-12	CE-U4	Voltage -12V (CE)	0.01 V/mV
8	U+28	CE-U5	Voltage +28V (CE)	0.01 V/mV
9	UCDP	CE-U6	Voltage +5V (C-DPU)	0.002 V/mV
10	URAD	CA-U2	Total Dose (RadFET)	0.002 V/mV
11	I+05	CE-I1	Current +5V (CE)	0.5 mA/mV
12	I-05	CE-I2	Current –5V (CE)	0.05 mA/mV
13	I+12	CE-I3	Current +12V (CE)	0.25 mA/mV
14	I-12	CE-I4	Current -12V (CE)	0.05 mA/mV
15	I+28	CE-I5	Current +28V (CE)	0.025 mA/mV
16	CEID	CE-ID	0xB5E5	n/a
17	TPCB	CA-T7	CASSE Board Temperature	T(x) °C/V (*)
18	CLTC	CE-C1	Last Telecommand received	n/a
19	CBTC	CE-C2	Last but one Telecommand	n/a
20	LMID	n/a	SESAME Local Time (midth word)	n/a (**)
21	LLOW	n/a	SESAME Local Time (low word)	n/a (**)
22	TT-Y	CA-T1	Foot –Y / TRM Temperature	T(x) °C/V (*)
23	TA-Y	CA-T2	Foot –Y / ACC Temperature	T(x) °C/V (*)
24	TT+X	CA-T3	Foot +X / TRM Temperature	T(x) °C/V (*)
25	TA+X	CA-T4	Foot +X / ACC Temperature	T(x) °C/V (*)
26	TT+Y	CA-T5	Foot +Y / TRM Temperature	T(x) °C/V (*)
27	TA+Y	CA-T6	Foot +Y / ACC Temperature	T(x) °C/V (*)
28	PPD	PP-D	Electron Density	n/a
29	SUPS	CE-F1 (different contents)	SRAM Usage / Power Status	see separate description
30	TIBO	CE-F2 (diff. contents)	Time since Boot [seconds]	see separate description
31	ERRF	CE-F3 (diff. contents)	Error Flags	see separate description

Notes:

(*) Currently, the transfer function

$$T(x) = 3384 - 4.392 \cdot \sqrt{593605 - 16100 \cdot (x + 0.6828)}$$

is used for FM hardware, where *T* designates the temperature in degree centigrade [°C] and *x* designates the unscaled analogue raw value in volt [V].

(**) SESAME Local Time is derived from the Lander Onboard Time (LOBT), which is received by a CDMS RTIM message. If no RTIM message has arrived (flag TI in ERRF), parameters with format count 20, 21 contain the time since boot.

(***) HK parameters U+05 and UP+5 can be used to determine the current consumption of the PP digital electronics. The difference between UP+5 and the incoming +5 V supply voltage (i.e. the value of U+05) is the voltage drop caused by the current through a 11.1 Ohm resistor; the current can thus be calculated as IP+5 = (U+05 - UP+5) / 11.1.

Parameter SUPS: Instruments Power Status and SRAM Usage

Housekeeping Parameter Word SUPS															
15	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
o	**data page no**				**P2**	**P1**	**P0**	**-**	**D2**	**D1**	**D0**	**C3**	**C2**	**C1**	**C0**
SRAM usage					**PP-PWR**				**DIM-PWR**			**CASSE-PWR**			

CASSE-PWR: Contents of CASSE power register
- C0: ±5 V supply voltage (RAM, analogue circuits) ON (1), OFF (0)
- C1: +28 V supply voltage ACC -Y ON (1), OFF (0)
- C2: +28 V supply voltage ACC +X ON (1), OFF (0)
- C3: +28 V supply voltage ACC +Y ON (1), OFF (0)

(cf. “CASSE FM PCB User Guide” RO-LSE-UG-3821)

DIM_PWR: DIM power settings
- D0: ±5 V supply voltage via DIM select line ON (1), OFF (0)
- D1: /PWR_AMP in DIM control1 register; power supply to log amplifier, segment switches and average circuit; power on (0), power off (1) [sic!]
- D2: /PWR_BURST in DIM control1 register; power supply to threshold circuit, event comparator and offset-circuit of peak detector; power on (0), power off (1) [sic!]

Note: D1 and D2 denote the last register adjustments by flight software, after DIM was switched on for the first time. As long as DIM is turned off via the DIM select line (D0 = 0), they do not represent the actual DIM power status.

PP_PWR: Contents of PP power register
- P0: ±12 V for transmitter ON (1), OFF (0)
- P1: ±5 V for receiver ON (1), OFF (0)
- P2: ±5 V for Langmuir Probe ON (1), OFF (0)

Note: P0 to P2 denote the last register adjustments by flight software. As PP can be operated with automatic power-off, the flags can - for a certain time period - represent a different than the actual power status.

SRAM Usage

Data page no**:** currently used SESAME SRAM data page for science data (0: less than one SD packet is waiting for transfer to CDMS)

o = 1: Memory overflow; SESAME SRAM currently exhausted by science data and temporary data

Parameter TIBO: Time since Boot

Time since boot of SESAME flight software (full seconds elapsed). Increases monotonously after boot (covers some 18 hours max.).

Parameter ERRF: Error flags

Deviating from all other HK parameters, ERRF does not provide a snapshot of the situation at a particular point in time but collects information about the status of the CDMS-SESAME software interface during a time period (namely between two successive HK measurements). A set flag (bit value = 1) shows, that at least one error of the kind indicated by the bit position occurred between the time-stamps of the previous and the current HK parameter set.

Housekeeping Parameter Word ERRF															
SESAME Error Code									***CDMS Error Code***						
.15	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
ME	**SD**	**BB**	**TC**	**TR**	**AD**	**TI**	**RQ**	**IN**	**-**	**UO**	**SV**	**MF**	**RU**	**IP**	**IR**

SESAME Error Code

Selected accumulated SESAME errors occurred since preceding HK measurement:

IN: invalid action code received or address was not SESAME or BROADCAST
RQ: cannot submit request to CDMS or request not fulfilled by CDMS within 2 minutes
TI: no RTIM message received (yet)
AD: error during ADC
TR: error during send/receive trigger
TC: error during TC / STC processing
BB: error during read/write Backup RAM buffer
SD: error during science data processing
ME: Memory (data pages) exhausted

CDMS Error Code

Accumulated CDMS error codes received via the CDMS RERC (Receive Error Code Word) message (cf. CDMS Subsystem Specification RO-LCD-SP-3101).

IR: Illegal Request Code
IP: Illegal pointer, offset, number (TCMO, TBUF)
RU: Request undue (can not be accepted in this phase)
MF: Mass-memory full
SV: Science data volume exhausted
UO: Destination unit off

4.9 Interaction with other instruments

It was proposed by the SESAME software team that data exchange between SESAME and units APX, MUPUS and SD2 shall take place via the Backup RAM Buffer (cf. RO-LSE-TN-3403). SESAME flight software implements reading and writing of its own Backup RAM Buffer in CDMS memory and the reading of the Backup RAM Buffer of other units. Additionally the exchange of Trigger Words and reading of the System Status Table (containing the on/off status of units) are implemented (cf. chapter "Interface to the CDMS").

4.10 Time and Timers

4.10.1 Sources of Time Information

Absolute time information is provided by the CDMS: the least significant 32 bit of the Lander Onboard Time (LOBT) are delivered to SESAME by a RTIM message (every second in CDMS normal mode), the most significant 5 bits of the LOBT (which should change rather seldom) are contained in the System Status Table (coming with an RSST message). LOBT has a resolution of 1/32 seconds.

Three RTX timer/counters and a software loop are used for relative timing: during SESAME software initialization timer interrupts from counter **TCI1** are permanently enabled and set to 100 ticks/second. Each interrupt increments the contents of the 32-bit variable **`TIMER1_VAR`** by one, thus providing a resolution of 10 milliseconds. The content of **`TIMER1_VAR`** is used to calculate the SESAME Local Time and to adjust or measure time differences in the range of seconds to hours. Interrupts from timer counter **TCI2** are enabled only if required for the adjustment of delays in the range of milliseconds to seconds. A software loop is used to adjust delays in the range 8 to 1000 microseconds. The RTX counter **TCI0** is managed by the C-DPU BIOS and used for BIOS internal purposes, only.

4.10.2 Derived Time Information

For all actions, which require absolute time information and for timestamps in the SD stream, the SESAME Local Time is used. It is the sum of the LOBT delivered by the last CDMS RTIM message and the time elapsed since the arrival of this message, which is derived from **`TIMER1_VAR`.** SESAME Local Time is calculated each time routine **`GetLocalTime`** is invoked. It has a resolution of 1/32 seconds and consists of two words, containing the 16 upper and 16 lower bits, respectively.

For the adjustment of delays the routines **`SEC2`**, **`MSEC2`** and **`USEC2`** and the specialized routines **`CASLongWait`**, **`CASShortWait`**, **`DIMWaitMsec`**, **`DIMWaitUsec`** and **`PPWaitMes`** have been implemented. **`CASHKLongWait`** and **`WAIT_HK`** perform a HK measurement during the waiting period in case it is pending.

4.11 Integer Arithmetic and Mathematical Functions

SESAME software does not use floating point arithmetic, it calculates with 8, 16 and 32 bit integers. The majority of operators and routines for single and double integer calculations are contained in the LMI Forth core, however some routines have been added (e.g. **DU>**, **DU<** and some routines from algorithm 46 of Forth scientific library, http://www.taygeta.com/fsl/sciforth.html) in order to simplify and shorten calculations.

With a new data type called word array (proposed by Walter Schmidt) it is possible to simulate the flexibility of higher mathematical languages (like MathLab) with automatic vector length determination. The first vector element always contains the length of the remaining vector, i.e. the number of elements for which the operations should be performed. A set of Forth routines was established, which is used to create, manipulate, and evaluate data in word array (“warr”) format. All routines can be used without modifications in a WinForth environment or under the RTX2010 environment.

No trigonometric or transcendental functions are included in the LMI Forth core. Therefore mixed tabular-algorithmic approximations of sine and logarithmic functions have been implemented, which provide sufficient accuracy for the generation of the PP DAC table, the PP onboard evaluation (sine(x), x/sine(x)) and for the compression of DIM peak values (logarithm).

4.12 Error Handling

Error handling takes place on different levels: communication problems occurring during the low level data exchange with the CDMS are indicated in the housekeeping parameter ERRF as well as some other problems in low level software layers. Instrument malfunctions detected during measurements are registered in an Error Code Word or Byte, which is part of the measuring data submitted to earth. An appropriate software action upon a malfunction is executed, which may range from ignoring the error to the abort of a measurement. Some errors detected in common software parts, or with global impact, result in the formatting of an error message, which is processed like a science data packet and sent to earth. Different error levels are assigned to an error (e.g. warning, fatal), which indicate the severity. Warning level errors are benign and are healed by e.g. the substitution of an unexpected parameter value by a default value.

The instrument specific error codes, the format of an error message and the meaning of error codes in an error message are described in the chapter "Telecommands and Expected Science Data Output".

5 Telecommands and Expected Science Data Output

5.1 Common Telemetry Formats

5.1.1 Science Data Packet Header

The first word in each SESAME science data telemetry packet is reserved for the SESAME Science Data Packet Header, leaving 127 words for measurement data in the TM packet. The SD packet header word is used to indicate the transmission status (to CDMS) of the *preceding* SD telemetry packet. Its content is usually fixed to the pattern 0xEEFF. Any deviation from that pattern indicates an unexpected (not necessarily fatal) communication problem with the CDMS. Some bit positions have a special meaning:

Science Data Packet Header: Bit Structure															
15	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
1	**1**	**1**	**0**	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**S2**	**S1**	**CH**

CH = S1 = S2 = 1: No error during transmission of the previous SD packet to CDMS recognized.

CH cleared: Checksums calculated by SESAME and by CDMS differ for the previous science data packet.

S1 cleared: Sync-error CDMS-SESAME; an RSCS action code was received from CDMS, but less than 128 SD words were sent by SESAME to CDMS.

S2 cleared: Sync-error CDMS-SESAME; no RSCS action code was received from CDMS, but a complete SD packet (128 words) was sent to CDMS.

Note:
(1) A cleared bit in the SD packet header indicates a communication problem with CDMS, but not in any case corrupted data. E.g. for some reason the arrival of a RSCS-message (“Receive Science Data Checksum”) from CDMS can be delayed by more than the expected maximum period of time (two seconds).

(2) There is no SD packet header in telemetry packets generated by the Common DPU Debug Monitor.

5.1.2 Science Data Measurement Header

Each data section in science data telemetry generated by SESAME software (thus not the C-DPU Debug Monitor messages) starts with a header containing meta-information about type and origin of data, total length and a time stamp:

Science Data Measurement Header				
Item No.	**Byte No.**	**Meaning**	**Value**	**Remarks**
1	0 to 1	Sync	0xBCDE	Value indicates flight software version FM-2.
2	2 to 3	Sync	0xBCDE	
3	4 to 5	Measurement ID		= 0: “SESAME Ready Message” (boot message) = 0x7F00: error message Any other value is the command word of a TC; science data result from the execution of that telecommand.
4	6	*spare*		
5	7	Length of data (high byte)		Data length includes the Science Data Header, but not the Science Data Packet Header(s)
6	8 to 9	Length of data (low word)		
7	10 to 11	SESAME local time (high word)		Point in time, when data were generated or execution of the TC started; SESAME local time runs with a resolution of 31.25 msec and is synchronized with LOBT (mid and low word) each CDMS RTIM message.
8	12 to 13	SESAME local time (low word)		

5.2 CASSE Commanding and Telemetry

CASSE: Defined Telecommands
(all numerical values in this table are hexadecimal)

IDENT	Com-mand Word	Parameter Words			Description
		No	**Meaning**	**Valid Range**	
CAS_HC	1000	n/a	n/a	n/a	CASSE Health Check
CAS_MES	1100	n/a	n/a	n/a	CASSE measurement controlled by JOB_MES jobcard
CAS_RJC	1310	16 parameter words, which contain a CASSE jobcard (see text for further details).			CASSE Receive Jobcard. Overrides default JOB_MES jobcard with the jobcard given in the parameter words. Valid until the next CAS_RJC command arrives or SESAME is switched off. No SD are generated.
CAS_PWR SW	1501	1.	Power Mode	0000=Standby, 0001=all circuits on	CASSE power switching. No SD are generated.
CAS_TEST	1A03	Three parameters depending on S/W implementation			CASSE software and instrument debug mode. Used during hardware and software ground tests only. Functionality depends on tested item.

5.2.1 CASSE Health Check (CAS_HC)

CASSE health check is a regular CASSE sounding measurement with parameters fixed in the software code. The health check is used to determine the status of the CASSE sensors, transmitters and electronics. A ping (2000 Hz, duration 5 ms) is successively transmitted by the transmitters at each foot and simultaneously the accelerometer on the same foot (x, y, z axes; total listening duration per foot: 20 ms) is listening. The data volume is approx. 3116 (± 3) byte, if no fatal error has occurred.

Some portions of the expected telemetry output are present or not depending on the success of on-board instrument control and data processing, i.e. on the absence or occurrence of fatal errors. This is indicated in the following table and explained in chapter 5.2.6.

Note: CAS_HC telemetry data is formatted (and can be decommutated) according to the generic format of any CASSE measurement (cf. next chapter) except the measurement ID in the measurement header (which is 0x1000 and not 0x1100).

Expected SD output for CASSE Health Check (CAS_HC)				
Item No.	**Byte No.**	**Meaning**	**(Typical) Value (hex.)**	**Remarks**
1	0 to 13	SD measurement header	BCDE BCDE 1000 llll llll tttt tttt	
2	14 to 15	Block header: Parameters of jobcard	0707	
3	16 to 47	Parameters of jobcard		
4	48 to 49	Block header: Foot temperatures	1414	
5	50 to 51	Temperature Foot –Y, TRM	e.g. FEBD	Scaling approx. T[K] = (0.0459*X+304.7); e.g. X=0xFEBD= -323 => T1=290 K *(subject to change)*
6	52 to 53	Temperature Foot –Y, ACC		
7	54 to 55	Temperature Foot +X, TRM		
8	56 to 57	Temperature Foot +X, ACC		
9	58 to 59	Temperature Foot +Y, TRM		
10	60 to 61	Temperature Foot +Y, ACC		
11	+1 to +2	Block header: Burst measurement	2121	
12	+3	Frequency Divider	0C	Adjusted TFC Register Value
13	+4 to +5	Frequency Increment	0075	Adjusted SR1, SR2 Register Value
14	+6	(nchn-1) = No of Channels minus one	02	Adjusted SLTLA Register Value
15	+7 to +8	Adjusted Sound Frequency	07CF	Should be close to 0x07D0 (2000 Hz)
16	+9 to +12	Adjusted Sampling Frequency	0000 BB78	High word, low word; should be close to 3*16000 [= 48 kHz].
17	+13 to +16	Start Time of Measurement		High word, low word of SESAME Local Time
18	+17 to +20	Tlen: Total Length of Measurement minus one (# byte)	03C5	High word, low word (should be close to 965)
19	+21 to +22	Block header: channel data	6666	
next data block (items 20 and 21) appears three times (three sensor channels per foot)				
20	+1 to +4	dchn: Data Count for one Channel (# byte)	0000 0142	High word, low word (dchn = 320..323)
21	+5 to (+4 + dchn)	dchn Sensor Data for one Channel; data length: one byte	depending on sensor activation	

22	+1 to +2	Trigger Status	0000	
23	+3 to +4	Block Header: Error code	8888	
24	+5 to +6	Error code for measurement	0000	
25	+7 to +8	Block Header: Foot temperatures	1414	
26	50 to 51	Temperature Foot –Y, TRM	e.g. FEBD	Results of second temperature measurement; Scaling approx. T[K] = (0.0459*X+304.7); e.g. X=0xFEBD= -323 => T1=290 K
27	52 to 53	Temperature Foot –Y, ACC		
28	54 to 55	Temperature Foot +X, TRM		
29	56 to 57	Temperature Foot +X, ACC		
30	58 to 59	Temperature Foot +Y, TRM		
31	60 to 61	Temperature Foot +Y, ACC		

5.2.2 CASSE Measurement (CAS_MES)

Perform a CASSE measurement controlled by the CASSE jobcard JOB_MES. A default jobcard is copied from SESAME EEPROM to RAM at boot time. It can be overwritten using telecommand CAS_RJC. The actual setting of jobcard parameters is included in the telemetry data. The Forth code for the default jobcard:

```
\ default jobcard for measurement; can be temporarily modified by TC
CREATE JOB_MES
   43 C,   01 C,    \ ID,         SUB_ID
   00 C,   03 C,    \ STRT_COND,  REP_AVG
 03E8  , 0032  ,    \ SND_FREQ,   (SND_DURA; TRG_TIMEOUT)
 0640  ,   11 C,    \ SAMP_FREQ,  TX_STATUS
   07 C, 0000  ,    \ AMP_GAIN,   TRG_SRC
 0000  ,   40 C,    \ TRG_DLY,    TRG_PLEV
   C0 C, 0096  ,    \ TRG_NLEV,   MSR_DURA
 1007  , 0000  ,    \ RX_STATUS,  GPW1
 0000  , 0000  ,    \ GPW2,       GPW3
   7F C,   00 C,    \ FTEMP_CH,   PAG_OBUF
 0000  ,            \ ADR_OBUF
```

Some portions of the expected telemetry output are present or not depending on the success of on-board instrument control and data processing, i.e. on the absence or occurrence of fatal errors. This is indicated in the following table and explained in chapter 5.2.6.

Expected SD output for CASSE Measurements (CAS_MES)				
Item No.	**Byte No.**	**Meaning**	**(Typical) Value**	**Remarks**
1	0 to 13	SD measurement header	BCDE BCDE 1100 llll llll tttt tttt *(hexadecimal)*	
2	14, 15	Block header: Parameters of jobcard	0x0707	
3	16 to 47	Parameters of jobcard		
4	48, 49	Block header: Foot temperatures	0x1414	
5	50 to 51	Temperature Foot –Y, TRM	e.g. 0xFEBD	FM-scaling approx. T[K] = (0.0459*X+304.7); e.g. X=0xFEBD= -323 => T1=290 K
6	52 to 53	Temperature Foot –Y, ACC		
7	54 to 55	Temperature Foot +X, TRM		
8	56 to 57	Temperature Foot +X, ACC		
9	58 to 59	Temperature Foot +Y, TRM		
10	60 to 61	Temperature Foot +Y, ACC		
Remaining data (11 to 18) appear for each measurement (number of measurements according to jobcard). Data corrupted (unknown bit set in the error code word (item 16 in Burst Mode Data Block or item 3 or item 25 in Triggered Mode Data Block), or "channel data count" > 131072) stops the loop over measurements. If channel data count ns is corrupted, use previous "channel data count" to read end of measurement then stop the loop. In this case only one foot temperature block can follow (if commanded).				
11	BURST MODE *or* TRIGGERED MODE DATA BLOCK *(see separate tables)*			
Items 12 to 18 only, if an additional (final) temperature measurement is commanded in the jobcard.				
12	+1 to +2	Block Header: Foot temperatures	0x1414	
13	+3 to +4	Temperature Foot –Y, TRM	e.g. 0xFEBD	FM-scaling approx. T[K] = (0.0459*X+304.7); e.g. X=0xFEBD= -323 => T1=290 K
14	+5 to +6	Temperature Foot –Y, ACC		
15	+7 to +8	Temperature Foot +X, TRM		
16	+9 to +10	Temperature Foot +X, ACC		
17	+11 to +12	Temperature Foot +Y, TRM		
18	+13 to +14	Temperature Foot +Y, ACC		

DATA BLOCK: BURST MODE DATA						
Item No.	**Byte No.**	**Length [Byte]**	**Data Type**	**Name**	**Value**	**Remarks**
1	0 to 1	2	UW	Block Header	0x2121	Burst data: Listening or Sounding Mode
2	2	1	UB	Frequency divider	0 to 15	Adjusted TFC Register Value (=0 only allowed when in Listening Mode)
3	3 to 4	2	UW	Frequency increment	1 to 1312	Adjusted SR1, SR2 Register Value
4	5	1	UB	(nchn-1)	0 to 11	Number of sensor channels minus one
5	6 to 7	2	UW	Adjusted sound frequency]	0 to ca. 5000	Transmitter frequency [Hz]; = 0 in Listening Mode
6	8 to 9	2	UW	Adjusted sampling frequency (high word)	<= 100000 / nchn	Sampling frequency [Hz] per sensor channel
7	10 to 11	2	UW	Adjusted sampling frequency (low word)		
8	12 to 13	2	UW	Start time of measurement (high word)		SESAME local time
9	14 to 15	2	UW	Start time of measurement (low word)		
10	16 to 17	2	UW	Total length (# byte) of measurement data minus one (high word)	$< 2^{17}$	= FIFO RAM address when recording stopped
11	18 to 19	2	UW	Total length (# byte) of measurement data minus one (low word)		
12	20 to 21	2	UW	Block Header	0x6666	Channel data (time series)
Next data block (item 13) for each channel in measurement (i.e. nchn times)						
13	DATA BLOCK: CHANNEL DATA *(see separate table)*					
14	+1 to +2	2	UW	Trigger status	0 to 4095	
15	+3 to +4	2	UW	Block Header	0x8888	Error Code Block
16	+5 to +6	2	UW	Error Code for measurement		

Data types: UW (unsigned word), UB (unsigned byte)

DATA BLOCK: TRIGGERED MODE DATA						
Item No.	**Byte No.**	**Length [Byte]**	**Data Type**	**Name**	**Value**	**Remarks**
1	0 to 1	2	UW	Block Header	0x2222	Triggered Mode Data
2	2 to 3	2	UW	Block Header	0x8888	Error Code Block
3	4 to 5	2	UW	Error Code		Error status after initialisation
Items 4 to 25 occur only if no fatal error EB_FATAL_MES in error code word (item 3)						
4	6	1	UB	Frequency Divider	0 to 15	Adjusted TFC Register Value
5	7 to 8	2	UW	Frequency Increment	1 to 1312	Adjusted SR1, SR2 Register Value
6	9	1	UB	(nchn-1)	0 to 11	Number of sensor channels minus one
7	10 to 11	2	UW	Trigger Status	0 to 4095	Contents of Trigger Status Register at time of trigger
8	12 to 13	2	UW	tim_burston_hi		SESAME Local Time at start of recording; high word
9	14 to 15	2	UW	tim_burston_lo		SESAME Local Time at start of recording; low word
10	16 to 17	2	UW	tim_trigger_hi		SESAME Local Time when trigger occurred; high word
11	18 to 19	2	UW	tim_trigger_lo		SESAME Local Time when trigger occurred; low word
12	20 to 21	2	UW	tim_burstoff_hi		SESAME Local Time at stop of recording; high word
13	22 to 23	2	UW	tim_burstoff_lo		SESAME Local Time at stop of recording; low word
14	24 to 25	2	UW	fifo_trigger_hi	0 to 131071	FIFO RAM address when trigger occurred; high word
15	26 to 27	2	UW	fifo_trigger_lo		FIFO RAM address when trigger occurred; low word
16	28 to 29	2	UW	fifo_burstoff_hi	0 to 131071	FIFO RAM address when recording stopped; high word
17	30 to 31	2	UW	fifo_burstoff_lo		FIFO RAM address when recording stopped; low word
18	32 to 33	2	UW	fifo_firstdat_hi	0 to 131071	FIFO RAM address of very first channel data; high word
19	34 to 35	2	UW	fifo_firstdat_lo		FIFO RAM address of very first channel data; low word
20	36 to 37	2	UW	Total length (# byte) of measurement data minus one (high word)	$< 2^{17}$	
21	38 to 39	2	UW	Total length (# byte) of measurement data minus one (low word)		
22	40 to 41	2	UW	Block Header	0x6666	Channel data (time series)

Data Block: Triggered Mode Data (continued)

Next data block (item 23) for each channel in measurement (i.e. nchn times)						
23	DATA BLOCK: CHANNEL DATA *(see separate table)*					
24	+1 to +2	2	UW	Block Header	0x8888	Error Code Block
25	+3 to +4	2	UW	Error Code		Error status after measurement

DATA BLOCK: CHANNEL DATA						
Item No.	**Byte No.**	**Length [Byte]**	**Data Type**	**Name**	**Value**	**Remarks**
1	0 to 1	2	UW	Channel data count (high word)	1 to 131072	*ns* = Number of samples in time series of channel
2	2 to 3	2	UW	Channel data count (low word)		
Next item (item 3) appears ns times						
3	+1	1	UB	Time series sample	-127 to +127	

Data types: UW (unsigned word), UB (unsigned byte)

5.2.3 CASSE Read Jobcard (CAS_RJC)

The jobcard parameters contained in the parameter words override the default jobcard JOB_MES. The new settings in JOB_MES are valid until another CAS_RJC command arrives or until SESAME is switched off. After hardware reset the default jobcard becomes active again. The order of jobcard parameters in the parameter words of CAS_RJC correspond to the byte order of parameters in the JOB_MES structure.
No science data are generated.

5.2.4 CASSE Power Switch (CAS_PWRSW)

CAS_PWRSW is used for switching the power supply for the CASSE RAM and analogue circuits (±5 V) and the accelerometers (28 V) [used mainly for testing / H/W debugging]. No science data are generated.

5.2.5 CASSE Error Codes

Error codes are composed of the following bit settings, e.g. Error Code 0x03 = (EB_FREQ | EB_DIVRAT) indicates a non fatal error during adjustment of sounding and sampling frequency.

CASSE Error Codes		
Value (hex)	**Name**	**Meaning**
0001	EB_FREQ	Invalid frequency increment (adjustment of sampling frequency); default (= 1312) used.
0002	EB_DIVRAT	Invalid frequency divider (adjustment of sounding frequency); default (= 1) used.
0004	EB_CDPU_ADC	Error during temperature A/D conversion.
4008	EB_NCHAN	Fatal: Invalid number of sensor channels
4010	EB_TIMEO	Fatal: Time-out during triggered mode.
4020	EB_NOSTRT	Fatal: Measurement start condition not fulfilled.
8040	EB_RAMOVR	Fatal: Allocated SESAME SRAM space exhausted.
4000	EB_FATAL_MES	Fatal error or time-out; current measurement will be aborted.
8000	EB_FATAL_SEQ	Fatal error; entire sequence of measurements (controlled by one jobcard) will be aborted.

5.2.6 CASSE Telemetry in Case of Fatal Errors (CAS_HC and CAS_MES)

One CASSE jobcard can define a series of CASSE measurements. The onboard processing of a jobcard defining a series of *n* measurements will usually lead to *n* equally structured data sections in telemetry. There are two types of fatal errors, which cause that different portions of the telemetry are skipped. When a fatal sequence error occurs (bit EB_FATAL_SEQ set in error code word), the processing of the entire measurement sequence is stopped and telemetry ends with the error code block indicating the fatal sequence error, possibly followed by one foot temperatures block (if additional temperature measurements were enabled in the jobcard).

A fatal measurement error (bit E_FATAL_MES set) does not abort the entire measuring sequence; it just aborts the running measurement. Depending on the instrument mode some data of the running measurement will not be acquired and thus not included into telemetry. The processing of further measurements in the sequence (if any) will continue.

5.3 DIM Instrument

DIM: Defined Telecommands (all numerical values in this table are hexadecimal)					
IDENT	**Command Word**	**Parameter Words**			**Description**
		No	**Meaning**	**Valid Range**	
DIM_PC	3000	n/a	n/a	n/a	Power Check
DIM_NT	3100	n/a	n/a	n/a	Noise Test
DIM_ST	3202	1	Margin	0000..0046	Sensor Test
		2	Direction	0000=X, 0001=Y, 0002=Z	
DIM_CA	3302	1	Margin (low level)	0000..0046	Calibration
		2	Margin (high level)	0000..0046	
DIM_AV	3404	1	Direction	0000=X, 0001=Y, 0002=Z	Average Continuous Measurement
		2	Energy control	0000=no limit, 0001=limited, 0002=distributed	
		3	Sampling time [sec]	> 0; less than T_AVER_SETTL not meaningful	
		4	Measuring time [sec]	> 0	
DIM_PWRSW	3501	1	Power Mode	0000=power off 0001=power on	Power switching (no SD are generated)
DIM_BC	3606	1	Direction	0000=X, 0001=Y, 0002=Z	Burst Continuous Measurement (storage of measured values in (U,T) matrix)
		2	Margin	0000..0046	
		3	Energy control	0000=no limit, 0001=limited, 0002=distributed	
		4	Signal decay time [msec]	0 < t < 00FF	
		5	Sampling time [sec]	= 0: no sampling > 0: sampling	
		6	Measuring time [sec]	> 0	
DIM_HC	3A03	1	Margin (low level calibration)	0000..0046	Health Check
		2	Margin (high level calibration))	0000..0046	
		3	Margin (Sensor Test)	0000..0046	

DIM: Defined Telecommands (all numerical values in this table are hexadecimal)					
DIM_MES	3F02	1	Nominal total execution time [s]	> 77; for significant Burst Continuous measurements: > 12c	DIM Autonomous Measuring Mode
		2	Sensor signal decay time [ms]	1 < t < 00FF	
DIM_BCTEST	3C06	1.	Direction	0000=X, 0001=Y, 0002=Z	Burst Continuous Measurement Test Mode (verbose output of measured values for each event)
		2.	Margin	0000..0046	
		3.	Energy control	not evaluated	
		4.	Decay time [msec]	0 < t < 00FF	
		5.	Sampling time [sec]	not evaluated	
		6.	Measuring time [sec]	> 0	
DIM_SPEC	3D02		2 parameters (variable)		Used for S/W and H/W debugging only.

5.3.1 DIM Power Check (DIM_PC)

DIM Power Test verifies that DIM supply voltages are within predefined limits on DIM board.

Expected SD output for DIM Power Check				
Item No.	**Byte No.**	**Meaning**	**(Typical) Value (hex.)**	**Remarks**
1	0 to 13	SD header	BCDE BCDE 3000 0000 0018 tttt tttt	Total length: 0x18 = 24 byte; last two words are SESAME Local Time
2	14, 15	Block header: Power Check Data	6363	
3	16, 17	Voltage on +5V line	e.g. 1388	Voltage in HK format; e.g. 0x1388 => 5000 mV
4	18, 19	Voltage on -5V line	e.g. 5388	Voltage in HK format; e.g. 0x5388 => -5000 mV
5	20	Error Code	e.g. 00	EB_BAD_HEALTH if power out of limits
6	21, 22	Block delimiter: end of Power Check Data	9C9C	
7	23	Padding character	00	

5.3.2 DIM Noise Test (DIM_NT)

DIM Noise Test measures electronic noise on DIM amplifier.

Expected SD output for DIM Noise Test				
Item No.	**Byte No.**	**Meaning**	**(Typical) Value (hex.)**	**Remarks**
1	0 to 13	SD header	BCDE BCDE 3100 0000 0014 tttt tttt	Total length: 0x14 = 20 byte; last two words are SESAME Local Time
2	14, 15	Block header: Noise Test Data	1818	
3	16	Margin [dB], for which no amplifier noise was measured	e.g. 1E	Margin range is 0-70 dB. Lower margin means less noise on amplifier (typ. 20 to 40 dB).
4	17	Error Code	e.g. 00	
5	18, 19	Block delimiter: end of Noise Test data	E7E7	

5.3.3 DIM Sensor Test (DIM_ST)

An electric pulse is applied to one of the three sensing faces of the DIM sensor, and the response is measured. Parameters are margin, which determines the detection threshold of the measuring amplifier, and the direction (x, y, z in DIM coordinate system).

Expected SD output for DIM Sensor Test				
Item No.	**Byte No.**	**Meaning**	**(Typical) Value (hex.)**	**Remarks**
1	0 to 13	SD header	BCDE BCDE 3202 0000 0020 tttt tttt	Total length: 0x20 = 32 byte; last two words are SESAME Local Time
2	14 to 15	Block header:	3636	
3	16	Direction/Margin		Bits 7,6,5: Direction (100: x, 010: y, 001: z) Bits 2,1,0: Margin divided by ten
4	17	Error Code	00	
5	18 to 19	Data Block Header	7272	
6	20 to 21	Average signal [mVolt]	0 to 3000 decimal	
7	22 to 23	Signal peak voltage [mVolt]	0 to 3000 decimal	
8	24 to 25	Impact time [timer count TC]	2 to 500 decimal	tc [µs] = TC / 20
9	26	Average Sample [dB]	0 to 100 decimal	
10	27	Signal peak voltage [dB]	0 to 83 decimal	
11	28	Impact time [dB]	10 to 70 decimal	
12	29 to 30	Block delimiter: end of Sensor Test data	C9C9	
13	31	Padding character	00	

5.3.4 DIM Calibration (DIM_CA)

Two electric pulses (low level and high level) are applied to the input of the measuring circuit. If the measured peak voltage and impact time values exceed predefined limits, the procedure is repeated (up to a total of four trials per calibration level). The calibration is successful, if there is one trial with error code = 0 for each calibration level.

Expected SD output for DIM Calibration				
Item No.	**Byte No.**	**Meaning**	**(Typical) Value (hex.)**	**Remarks**
1	0 to 13	SD header	BCDE BCDE 3302 llll llll tttt tttt	llll = total length; last two words are SESAME Local Time
2	14 to 15	Block header:	2727	
3	16	Low Margin	1E	
4	17	High Margin	32	
next data block (item 5 to 12) may occur up to eight times				
5	+1 to +2	Data Block Header	7272	
6	+3	Margin		
7	+4	Level		0x00 = Low, 0xFF = High
8	+5 to +6	Timer Count		
9	+7 to +8	Peak Voltage [mVolt]		
10	+9	Time [dB]		
11	+10	Peak Voltage [dB]		
12	+11	Error Code for one trial	00	
13	+1 to +2	Total error (summed over all trials)		
14	+3 to +4	Block delimiter: end of Calibration data	D8D8	
next item (# 15) occurs only if the total number of bytes so far (from items 1 to 14) is odd, i.e. the number of calibration trials (equals the number of blocks #5 to #12) is odd.				
15	+5	Padding character	00	

5.3.5 DIM Average Continuous (DIM_AV)

Samples of the average signal voltage are measured for one sensor direction. The sampling time denotes the interval between measurements of the signal average. The signal is averaged during T_AVER_SETTL = 4 seconds (fixed in software code).

Expected SD output for DIM Average Continuous Mode (DIM_AV)				
Item No.	**Byte No.**	**Meaning**	**(Typical) Value (hex.)**	**Remarks**
1	0 to 13	SD header	BCDE BCDE 3404 llll llll tttt tttt	llll = total length depending on measuring and sampling time; last two words are SESAME Local Time
2	14, 15	Block header: Average Continuous	4545	
3	16	Direction	00 (x) or 01 (y) or 02 (z)	Echoed Command Parameter
4	17	Energy Control	00 or 01 or 02	Echoed Command Parameter
5	18, 19	Sampling Time [s]		Echoed Command Parameter
6	20, 21	Measuring Time [s]		Echoed Command Parameter
7	22, 23	Data Block header	7272	
8	24, 25	Sampling Time [s]		
9	26, 27	nsamp: Number of measured samples		
next data block (item 10) occurs nsamp times				
10	+1	Average Sample [dB]		
11	+1 to +2	Time after final sampling (high word)		SESAME Local Time
12	+3 to +4	Time after final sampling (low word)		
13	+5	Error Code		
14	+6, +7	Block delimiter: Average Continuous data	BABA	
next item (# 15) occurs only if the total number of bytes so far (from items 1 to 14) is odd, i.e. the number of samples (item 9) is even.				
15	+8	Padding character	00	

5.3.6 DIM Power Switch (DIM_PWRSW)

Switching of DIM ±5 V power supply. A simple interface circuit on DIM PCB is not affected; it is always powered if SESAME is powered.
No science data are generated.

5.3.7 DIM Burst Continuous (DIM_BC)

Single events on one sensor face are registered. Measured values (peak amplitude U and impact time T) are stored in a compressed way. First they are logarithmically scaled to 1 <= U[dB] <= 90 dB and 10 <= T[dB] <= 70. The counts for events with a particular (U[db], T[db]) combination are stored in memory cells of different sizes (one word, one byte, one nibble = 4 bit), depending on the expected frequency of such events. The resulting matrix of packed counts has a fixed size of 3585 byte (independent of the actual number of events). Additionally average samples can be measured.

The sampling time denotes the interval between measurements of the signal average. The signal is averaged during T_AVER_SETTL = 4 seconds (fixed in software code). The instrument is not sensitive for single impacts while averaging. Thus the sampling time should be chosen large enough (>> T_AVER_SETTL) to leave gaps for significant measurements of single impacts. Each Burst Continuous Mode starts with a 10 seconds instrument warm-up period, which is not included in the measuring time.

Expected SD output for DIM Burst Continuous Mode (DIM_BC)				
Item No.	**Byte No.**	**Meaning**	**(Typical) Value (hex.)**	**Remarks**
1	0 to 13	SD header	BCDE BCDE 3606 llll llll tttt tttt	llll = total length; last two words are SESAME Local Time
2	14, 15	Block header:	5454	
3	16	Direction	00 (x) or 01 (y) or 02 (z)	Echoed Command Parameter
4	17	Margin		Echoed Command Parameter
5	18	Energy Control	00 or 01 or 02	Echoed Command Parameter; not used in S/W
6	19	Signal decay Time [ms]		Echoed Command Parameter
7	20, 21	Sampling Time [s]		Echoed Command Parameter
8	22, 23	Measuring Time [s]		Echoed Command Parameter
9	24, 25	Data Block header	7272	
10	26, 27	Number of Events detected		
11	28, 29	Number of false Events		
12	30, 31	Number of long Events		
13	32, 33	nsamp: Number of Average Samples		
next data block (item 14) occurs nsamp times				

14	+1	Average Sample [dB]		
15	+1 to +2	Time at end of measuring period (high word)		SESAME Local Time
16	+3 to +4	Time at end of measuring period (low word)		
17	+5	Error Code	00	
18	+1 to +440	220 event counts for 0<U[db]<21 and 9<T[db]<21		Data size: one word; order of (U[db], T[db]) pairs: (1,10),(2,10),(3,10),..., (19,20),(20,20)
19	+441 to +840	400 event counts for 0<U[db]<21 and 20<T[db]<41		Data size: one byte; order of (U[db], T[db]) pairs: (1,21),(2,21),(3,21),..., (19,40),(20,40)
20	+841 to +1460	620 event counts for 20<U[db]<41 and 9<T[db]<41		Data size: one byte; order of (U[db], T[db]) pairs: (21,10),(22,10),(23,10), ...,(39,40),(40,40)
21	+1461 to +2060	1200 event counts for 0<U[db]<41 and 40<T[db]<71		Data size: one nibble (4 bit); order of (U[db], T[db]) pairs: (1,41),(2,41),(3,41), ...,(39,70), (40,70); in a byte, the low nibble (bits 0..3) refers to the lower U[db] value.
22	+2061 to +3585	3050 event counts for 40<U[db]<91 and 9<T[db]<71; data length: one nibble		Data size: one nibble (4 bit): order of (U[db], T[db]) pairs: (41,10),(42,10),(43,10), ...,(89,70),(90,70); in a byte, the low nibble (bits 0..3) refers to the lower U[db] value.
23	+1, +2	Block delimiter: Burst Continuous data	ABAB	
next item (# 24) occurs only if the total number of bytes so far (from items 1 to 23) is odd, i.e. the number of average samples (item 13) is odd.				
24	+3	Padding character	00	

5.3.8 DIM Health Check (DIM_HC)

DIM Health check performs DIM Power Check and, if no error during Power Check occurred, subsequently the sequence DIM Noise Test, DIM Calibration, DIM Sensor Test (X segment), DIM Sensor Test (Y segment), DIM Sensor Test (Z segment). Science data generated are composed of the data of the single procedures.

5.3.9 DIM Burst Continuous Test Mode (DIM_BCTEST)

Expected SD output for DIM Burst Continuous Test Mode (DIM_BCTEST)				
Item No.	**Byte No.**	**Meaning**	**(Typical) Value (hex.)**	**Remarks**
1	0 to 13	SD header	BCDE BCDE 3C06 llll llll tttt tttt	llll = total length; last two words are SESAME Local Time
2	14, 15	Block header:	5454	
3	16	Direction	00 (x) or 01 (y) or 02 (z)	Echoed Command Parameter
4	17	Margin		Echoed Command Parameter
5	18	Energy Control	00 or 01 or 02	Echoed Command Parameter; not used.
6	19	Decay Time [ms]		
7	20, 21	Sampling Time [s]		Echoed Command Parameter
8	22, 23	Measuring Time [s]		Echoed Command Parameter
9	24, 25	Data Block header	7272	
10	26, 27	nevent: Number of Events detected		
11	28, 29	Number of false Events		
12	29, 30	Number of long Events		
13	32, 33	Number of Average Samples	0000	
next data block (item 14 to 17) occurs nevent times				
14	+1, +2	Timer Count		
15	+3, +4	Peak Amplitude [mVolt]		
16	+5	Timer [dB]		
17	+6	Peak Amplitude [dB]		
18	+1 to +2	Time at end of measuring period (high word)		SESAME Local Time
19	+3 to +4	Time at end of measuring period (low word)		
20	+5	Error Code	00	
21	+6, +7	Block delimiter: end of Burst Continuous data	ABAB	

Single events on one sensor face are registered. In DIM_BCTEST mode measured values are not stored in a compressed way (as in DIM_BC mode), but for each event the peak voltage (in mV and dB) and the impact time (timer count and time [dB]) are included in telemetry. No average samples are measured.

5.3.10 DIM Autonomous Measuring Mode (DIM_MES)

DIM Autonomous Mode starts with a health check (DIM_HC). The results of the health check are used to determine which of the three sensor faces can be used and which measuring mode (Burst Continuous or Average Continuous) is applicable for each of the sensor faces. The margin (sensitivity of measurement) is adjusted according to the result of the noise test (part of DIM_HC). In case Burst Continuous measurements shall be performed the margin is additionally checked with a short pre-measurement: In case the sum of long and false events exceeds the number of accepted (dust impact) events the margin is increased. The total measuring time is distributed among the single measurements for each working sensor face and the first and a concluding DIM_HC.

Science data generated by DIM_MES comprise the science data of the single measurements mentioned above. No extra data are generated.

5.3.11 DIM Error Codes

Error codes are composed of the following bit settings, e.g. Error Code 0x30 = (EB_CAL_LO | EB_BAD_CAL_HI) indicates an error during low level and high level calibration.

DIM Error Flags		
Flag (hex.)	**Name**	**Meaning**
01	EB_OVERCURR	Over-current interrupt detected (warning).
02	EB_NOISY_AMP	DIM_NT: Noise level higher than limit (70 dB).
02	EB_NO_AD_RDY	Error using ADC of C-DPU.
04	EB_NO_PULSE	DIM_ST: No pulse detected.
04	EB_BAD_HEALTH	DIM_PC: Voltage out of limits +-.[4.5, 5.5] V; fatal.
08	EB_LONG_T	Long pulse measured (DIM_CAL, DIM_ST, DIM_BC).
10	EB_BAD_CAL_LO	Calibration (low level) failed (U not in the range 33 to 49 dB or T not in the range 20 to 60 dB).
10	EB_NOISY_TEST	DIM_ST: Average sample exceeds limit (> 20 dB).
20	EB_BAD_CAL_HI	Calibration (high level) failed (U not in the range 71 to 83 dB or T not in the range 40 to 70 dB).
20	EB_BAD_TEST	DIM_ST: Peak voltage and signal length out of range (not in the range 40 to 70 dB).
40	EB_MEM_FULL	Allocated SESAME RAM memory space exhausted (fatal).
80	EB_OC_PWROFF	Excessive INT4 (over-current) interrupts; DIM instrument switched off (fatal).

5.4 PP Instrument

PP: Defined Telecommands					
IDENT	**Command Word (hex.)**	**Parameter Words**			**Description**
		No	**Meaning**	**Valid Range**	
PP_HC	5000	n/a	n/a	n/a	PP Health Check
PP_LM	5100	n/a	n/a	n/a	PP Langmuir Probe with different integration times
PP_AM2	6201	1	Electrode configuration: 0x0abi, with a=electrode for DAC output A, b=electrode for DAC output B, i=electrode used for current measurement (*).	a = 0, 1, 2 b = 0, 2, 3 (not equal to a) i = 0, 1, 2, ... ,7 with 1 = +X leg 2 = MUPUS PEN 3 = APX 5 to 7: see text 0 = return potential difference	PP Active Mode measurements with different transmitter frequencies and three output voltage amplitudes each (according to the PP control table); results of onboard data evaluation transmitted to ground.
PP_AMTEST2	6B04	1	Electrode configuration: 0abi, with a=electrode for DAC output A, b=electrode for DAC output B, i=electrode used for current measurement (*).	a = 0, 1, 2 b = 0, 2, 3 (not equal to a) i = 0, 1, 2, ... ,7 with 1 = +X leg 2 = MUPUS PEN 3 = APX 5 to 7: see text 0 = return potential difference	One PP active measurement with raw data output and onboard data evaluation.
		2	nominal TX frequency	20 to 11000 [Hz] (0x0014 to 0x2AF8)	
		3	no. of waves	3, 5, 7, ...,125	
		4	TX amplitude damping	0= full amplitude 1= half amplitude 2= ¼ amplitude	

PP_AMTEST	5B03	1	Electrode configuration: 0abi, with a=electrode for DAC output A, b=electrode for DAC output B, i=electrode used for current measurement (*).	a = 0, 1, 2 b = 0, 2, 3 (not equal to a) i = 0, 1, 2, ... ,7 with 1 = +X leg 2 = MUPUS PEN 3 = APX 5 to 7: see text 0 = return potential difference)	One PP active measurement with raw data output and onboard data evaluation; PP_AMTEST is equivalent to the PP_AMTEST2 command with the same parameters 1 to 3 and full transmitter current amplitude. Note: TM data appear under the header of PP_AMTEST2.
		2	Nominal TX frequency	20 to 11000 [Hz] (0x0014 to 0x2AF8)	
		3	No. of waves	3, 5, 7, ...,125	
PP_PM2	6301	1.	Spare (might be used as index to different control tables)		One PP passive measurement with on-board data evaluation. Note: The command parameter is currently not evaluated, but must be included (use e.g. 0xFFFF)
PP_PMTEST2	6C01	1	Exponent of two ***n*** such that the number of used samples ***ns*** is $ns = 2^n$ n = 10, 11, 12, 13 (0x0A to 0x0D)		One PP passive measurement with raw data output and on board data evaluation; the sampling frequency, the number of skipped samples and the number of frequency bins are read from the control table.
PP_PWRSW	5501	1	Power Mode	0000=all circuits off 0001=all circuits on	PP power switching used for H/W test / debugging (no SD are generated).
PP_DA	5802	1	Address	0018 *or* 0019	PP direct register address
		2	Value		
PP_SPEC	5D03		3 parameters (variable)		Used for debugging during S/W and H/W tests only.

(*) PP electrode configuration:

In Active Mode, PP uses 4 (of 5 available) electrodes for transmitting and receiving signals. The two receiver electrodes are mounted in the -Y and +Y landing gear feet. The connection of the receiver electrodes is fixed and thus there is no need to include their configuration neither in the TC nor in the TM.

Three electrodes are left: one is in the +X landing-gear foot, another one is mounted at the insertion end of the MUPUS hammering device PEN and the third electrode is mounted into the lid of the APX detector. Two of the electrodes can be selected for the insertion of a current into the cometary surface. To this end, one of these electrodes has to be connected to the TX A output of the PP central electronics, the other one to the TX B output. The TX A output is also called "direct output" or "DAC output A", the TX B output is also called "inverted output" or "DAC output B".

For current measurements, one of the three electrodes can be connected to the input of the receiver circuit in PP central electronics. For calibration and debug purposes, also other channels can be connected to the input.

Thus a number of combinations are possible, and one integer word is used to describe the electrode configuration (for TC and TM). Written as hex value 0x0abi, the first (most significant) digit of the word is always "0" and the next 3 digits describe the electrical configuration using indices of electrodes and channels.

a: electrode connected to the TX A output.

Possible values: 0 [none], 1 [+X leg], 2 [MUPUS PEN]

b: electrode connected to the TX B output.

Possible values: 0 [none], 2 [MUPUS PEN], 3 [APX]

i: input channel

Possible values:

0 [potential difference]

1 [current at +X leg]

2 [current at MUPUS PEN]

3 [current at APX]

4 [direct measurement at -Y foot]

5 [direct measurement at +Y foot]

6 [reference voltage -2.5 V]

7 [reference voltage +2.5 V]

Sub-parameter i can thus be any octal digit. This allows instrument descent calibration with code 0abi=0104 and 0abi=0105, which sends sinusoidal voltage variations between +X foot and lander ground and measures the response on the +Y-foot and -Y-foot, respectively. 6 and 7 would be reference voltages in case instabilities are suspected.

Example: electrode configuration is "0x0131": The first digit "0" means nothing but format is OK so far. The second digit "1" indicates TX A (=direct output=DAC output A) is connected to the +X foot electrode. The third digit "3" means TX B (=inverted output=DAC output B) is connected to the APX sensor. The fourth digit "1" means current measurement uses the +X foot electrode.

5.4.1 PP Health check (PP_HC)

During PP health check a variety of voltages and currents are measured on PP board, thus checking the electrical status of PP.

Expected SD output for PP Health Check (PP_HC)

Byte No.	Meaning	(Typical) Value (hex.)	Remarks
0 to 13	SD header	BCDE BCDE 5000 0000 0024 tttt tttt	Total length: 0x24 = 36 byte; last two words are SESAME Local Time
14, 15	Langmuir Probe with clock divider=0	e.g. 3A44	Depends strongly on environment and sensor location
16, 17	ADC offset	e.g. 0080	Should be close to 0x0080 (0x0080 represents zero with bipolar ADC)
18, 19	-2.5 V reference	e.g. 0051	Should be nearly symmetrical to ADC offset
20, 21	+2.5 V reference	e.g. 00AE	
22, 23	Differential value from +2.5V reference measurement	e.g. 0069	
24, 25	Direct voltage from receiver 1	e.g. 00FF without sensors connected	Depends on connection of receiver and environment
26, 27	Direct voltage from receiver 2	e.g. 00FF without sensors connected	Depends on connection of receiver and environment
28, 29	Transmitter current at electrode 1; no voltage applied	e.g. 0080	Should be close to ADC offset
30, 31	Transmitter current at electrode 2; no voltage applied	e.g. 0080	Should be close to ADC offset
32, 33	Transmitter current at electrode 3; no voltage applied	e.g. 0080	Should be close to ADC offset
34, 35	Error code	0	PP errors summed for all measurements.

5.4.2 PP Langmuir Probe Test (PP_LM)

Telecommand PP_LM initiates a series of Langmuir Probe measurements with different periods of charge collection. The magnitude of measured values depends strongly on electrode status and environmental conditions but the course of measured values related to the integration times gives strong evidence on the functionality of PP. This measurement sequence is mainly used for ground tests and is not a regular flight measurement.

Expected SD output for PP Langmuir Probe Test			
Byte No.	**Meaning**	**(Typical) Value (hex.)**	**Remarks**
0 to 13	SD header	BCDE BCDE 5100 0000 0052 tttt tttt	total length: 0x52 = 82 byte; last two words are SESAME Local Time
14, 15, 16, 17	1st byte: Integration clock divider (nominal value) 2nd byte: Integration clock divider (actual value) 3rd –4th byte: measured electron density	0000 3A44	Nominal clock divider value and actual value (read back from register) must be equal. Measured value of electron density should decrease linearly with increasing clock divider value.
18, 19, 20, 21	1st byte: Integration clock divider (nominal value) 2nd byte: Integration clock divider (actual value) 3rd –4th byte: measured electron density	0101 1D38	
22, 23, 24, 25	1st byte: Integration clock divider (nominal value) 2nd byte: Integration clock divider (actual value) 3rd –4th byte: measured electron density	0202 137C	
(...)			
74, 75, 76, 77	1st byte: Integration clock divider (nominal value) 2nd byte: Integration clock divider (actual value) 3rd –4th byte: measured electron density	0F0F 03A8	
78, 79, 80, 81	1st byte: Integration clock divider (nominal value) 2nd byte: Integration clock divider (actual value) 3rd –4th byte: measured electron density	0404 0BB5	Measurement with default clock divider value (15); result should be similar to already measured value with clock divider=15.

5.4.3 PP Active Mode 2 (PP_AM2)

A series of active PP measurements is performed and a modified wavelet method is used on-board to analyse the time series of each measurement. All measurement parameters except the electrode configuration are taken from the PP control table in C-DPU EEPROM or are fixed in the software code.

Expected SD output for PP Active Mode 2 (PP_AM2)			
Byte No.	**Meaning**	**(Typical) Value**	**Remarks**
0 to 13	Science data header	BCDE BCDE 6201 0000 030C tttt tttt	Total length: 780 byte; last two words are SESAME Local Time
14, 15	Commanded electrode combination		Echoed command parameter
16, 17	Used electrode combination	for example: 0x0121, 0x0122, 0x0131, 0x0133, 0x0232, 0x0233	Used electrode combination checked for correct format and corrected if necessary
18, 19	Number of frequencies ***nfreq***	defined in the PP control table (1 to 20)	
for all frequencies (nfreq times):			
+1, +2	Nominal frequency		Nominal TX frequency [Hz]
for three adjusted transmitter signal amplitudes (tx_amp = 0, 1, 2):			
Active Mode Results Block			
+1, +2	Error code	0	Cf. list of error flags
if no fatal error in error code:			
+3	QUAL		Quality flags (cf. list of quality flags)
+4	NSPW		Number of points per wave
+5, +6	PHASE		Phase difference potential-current (1/16 degree)
+7, +8	Current amplitude		Scaling as raw data without offset: 128 = max. ADC current
+9, +10	Voltage amplitude		Scaling as raw data without offset: 128 = max. ADC voltage
+11, +12	Math Error Code		Cf. list of math error flags

Total data volume: 780 byte net (will be filled up to form 4 complete SD packets). Gross TM amount: 4*256 = 1024 byte (maximum TM amount (no fatal error) with ***nfreq***=20).

In case of fatal measurement error the data after the error code word (from QUAL to Math Error Code) will not be present in SD output; however the loops over the three different transmitter signal amplitudes and the transmitter frequencies continue.

5.4.4 PP Active Mode Test 2 (PP_AMTEST2)

One active PP measurement is performed. Adjusted and measured values (DAC table computed onboard, written to the instrument and read back from PP memory, time series of transmitter current and receiver voltage samples) are sent to ground. Telemetry concludes with the results of the on-board data evaluation. Adjustable parameters of command PP_AMTEST2 are the configuration of electrodes, the transmitting frequency and amplitude and the number of sine waves, which should be sent and recorded. Because telemetry contains the raw time series data and the results of the on-board evaluation of that data, it is possible to check both, details of the time series and the correct working of the data evaluation.

Expected SD output for PP Active Mode Test 2 (PP_AMTEST2)

Byte No.	Meaning	(Typical) Value	Remarks
0 to 13	Science data header	BCDE BCDE 6B04 llll llll tttt tttt	llll= total length (depends on command parameter settings); last two words are SESAME Local Time
14, 15	Electrode combination	For example: 0x0121, 0x0122, 0x0131, 0x0133, 0x0232, 0x0233	Command parameter (checked for correct format and corrected if necessary)
16, 17	Nominal TX Frequency [Hz]	20 to 11000 [Hz]	Echoed command parameter
18	Number of waves	3, 5, 7, ...,125	Command parameter (checked and corrected if less than 3)
19	TX output damping	0 or 1 or 2	Echoed command parameter
20, 21	ADC_DIV	31 to 4095	Adjusted clock divider for ADC
22, 23	ADC_ADR	255 + 2*NSPW*(number of waves)	Adjusted last address in PP memory
24, 25	DAC_DIV	20 to 2047	Adjusted clock divider for DAC
26	NSPW	16 or 32 or 64	Number of points per wave.
27	DAC_ADDR	1 to 255	Adjusted last used address in DAC table.

28, 29	Error code	0	
if no fatal error in error code:			
30 to 285	DAC table read back from PP memory	256 DAC table entries, each ranging from 0 to 255	Complete DAC table section in PP memory. Bytes #0 to byte (DAC_LADR) form the actually used DAC table.
286 to 287	Number of samples ***nsamp***	NSPW*(number of waves)	
nsamp times			
Active Mode Samples Block			
+1	Transmitter current sample	0..255	One byte per sample
+2	Receiver voltage sample	0..255	One byte per sample
Active Mode Results Block			
+1, +2	Error code	cf. list of error flags	
if no fatal error in error code:			
+3	QUAL	cf. list of quality flags	Quality flags
+4	NSPW		Number of points per wave
+5, +6	PHASE		Phase difference potential-current (1/16 degree)
+7, +8	Current amplitude		Scaling as raw data without offset: 128 = max. ADC current.
+9, +10	Voltage amplitude		Scaling as raw data without offset: 128 = max. ADC voltage.
+11, +12	Math Error Code	cf. list of math error flags	

5.4.5 PP Active Mode Test (PP_AMTEST)

Upon arrival of the PP_AMTEST command, flight software executes a PP_AMTEST2 measurement with transmitter amplitude damping set to 0 (i.e. full transmitting amplitude). Consequently telemetry data appear as a result of a PP_AMTEST2 measurement.

FM-2.0 supports command PP_AMTEST for downward compatibility.

5.4.6 PP Passive Mode 2 (PP_PM2)

Expected SD output for PP Passive Mode 2 (PP_PM2)			
Byte No.	**Meaning**	**(Typical) Value**	**Remarks**
0 to 13	Science data header	BCDE BCDE 6301 llll llll tttt tttt	llll= total length (depends on command parameter settings); last two words are SESAME Local Time
14, 15	TC command parameter		Command parameter (currently not used)
16, 17	LP integrator clock divider	1 to 15	Determines integrating time of Langmuir Probe (LP) measurement
18, 19	LP value	0 to 0xFFFF	Result of LP measurement
20, 21	Error Code	cf. list of PP error flags	Error code for LP measurement
22, 23	ADC clock divider	depending on the sampling frequency defined in the PP control table; usually 125 representing 40 kHz sampling frequency	Instrument adjustment calculated from the used sampling frequency
24, 25	Number of used samples ***ns*** (excluding skipped samples)	2^{10} to 2^{13}	Parameter read from PP control table
26, 27	Error Code		Error code for passive measurement
If no fatal error:			
Passive Mode Results Block			
28, 29	Number of frequency bins ***nbin***	0 to 10	
nbin times: ***Power spectrum block***			
+1 to +2	Spectrum bin power for n^{th} bin; high word		
+3 to +4	Spectrum bin power for n^{th} bin; low word		
+1, +2	Math Error Code		

5.4.7 PP Passive Mode Test 2 (PP_PMTEST2)

One passive PP measurement is performed. Adjusted and measured values (transmitter current and receiver voltage time series) are sent to ground. Telemetry concludes with the results of the on-board data evaluation.

Expected SD output for PP Passive Mode Test 2 (PP_PMTEST2)

Byte No.	Meaning	(Typical) Value	Remarks
0 to 13	Science data header	BCDE BCDE 6C01 llll llll tttt tttt	llll= total length (depends on command parameter settings); last two words are SESAME Local Time
14, 15	LP integrator clock divider	1 to 15	Determines integrating time of Langmuir Probe (LP) measurement
16, 17	LP value	0 to 0xFFFF	Result of LP measurement
18, 19	Error Code	cf. list of PP error flags	Command parameter errors and error flags for LP measurement
20, 21	ADC clock divider	depending on the sampling frequency defined in the PP control table; usually 125 representing a sampling frequency of 40 kHz	Instrument adjustment calculated from the used sampling frequency
22, 23	Number of used samples ***ns*** (excluding skipped samples)	2^{10} to 2^{13}	Interpreted command parameter
24, 25	Error Code	cf. list of PP error flags	Error flags for passive mode measurement

With a fatal error indicated in the Error Code (bytes 24, 25), telemetry stops here. If no fatal error:			
ns times: Samples block			
+1	n^{th} difference value	0 to 255	Sample read from even PP memory address
Passive Mode Results Block			
+1 to +2	Number of frequency bins ***nbin***	0 to 10	
nbin times: ***Power spectrum block***			
+1 to +2	Spectrum bin power for n^{th} bin; high word		
+3 to +4	Spectrum bin power for n^{th} bin; low word		
+1 to +2	Math Error Code		Errors encountered during PM data analysis; see list of math errors

5.4.8 PP Direct Hardware Access (PP_DA)

PP_DA is used to write and read PP registers directly (used for H/W debugging).

Expected SD output for PP Direct H/W Access (PP_DA)

Byte No.	Meaning	(Typical) Value (hex.)	Remarks
0 to 13	SD header	BCDE BCDE 5802 0000 0016 tttt tttt	Total length: 0x16 = 22 byte; last two words are SESAME Local Time
14, 15	Bus address	0018 or 0019	Echoed command parameter
16, 17	Parameter written to bus address		Echoed command parameter
18, 19	Value read from bus address		= -2 if wrong bus address
20, 21	Measured voltage on +5V power supply line	09C4	Multiply by 2 to yield voltage [mV]

5.4.9 Error Codes and Quality Flags

PP General Software Error Flags (TM parameter "PP Error Code")			
Flag (hex.)	**Flag (DEC(HEX XOR 8000))**	**Name**	**Meaning**
8001	1	EB_PPINVREG	Invalid register address.
8002	2	EB_PPVERREG	Error verifying register write.
8004	4	EB_PPPWRREG	Error accessing power register.
8008	8	EB_PPMUXSET	MUX setting not allowed.
8010	16	EB_PPMEMACC	Error accessing PP RAM.
8020	32	EB_PPMESRUN	Tried to start measurement but a measurement is already running.
0040	64	EB_PPWRITE	Error during writing to instrument.
0080	128	EB_PPREAD	Error during reading from instrument.
0100	256	EB_PPCDUADC	Error using ADC of C-DPU.
0200	512	EB_PPDACTAB	Error during DAC table generation.
0400	1024	EB_PPNSAMP	Calculated number of samples > N_SAMP_MAX.
8800	2048	EB_PPNOMEM	C-DPU memory exhausted.
9000	4096	EB_PPTOUT	Measurement time out.
2000	8192	EB_PPINVCMD	Invalid command parameter.
8000	0	EB_PPFATAL	Flag indicates fatal error.

A separate error code word ("PP Math Error Code") is used to indicate errors, which can only occur during on-board data reduction:

Errors which can occur during on-board data reduction ("PP Math Error")			
Flag (hex.)	**Flag (decimal)**	**Name**	**Meaning**
0001	1	EB_PPMATHNRED	Reduce: number of vector elements odd or less than 2; fatal.
0002	2	EB_PPMATHNEXP	Expand: less than four elements in input vector; fatal.
0004	4	EB_PPMATHNHIH	Too much data for analysis; truncating.
0008	8	EB_PPMATHNLOW	Too few data for analysis; padding with "128".
0010	16	EB_PPMATHPOW2	Used number of waves is not a power of 2; truncated.
0020	32	EB_PPMATHNFLT	Not the expected number of elements in filtered arrays; fatal.
0040	64	EB_PPMATHSINE	Argument for sine_table() not in valid range 0<= deg2 <=720.
0080	128	EB_PPMATHDSIN	Overflow in divsin() or result inexact.
0100	256	EB_PPMATHTRIM	Too few data for trimmed mean calculation; regular mean used.
0200	512	EB_PPMATHNODA	No data for warr.mean; particular: analysis yields no data.
0400	1024	EB_PPMATHNBIN	Passive mode: not enough data in bin.
0800	2048	EB_PPMATHNMEM	Not enough memory for data reduction.

More than one flag can be set in each error code word.

Quality flags are used to indicate saturated signals in active and passive modes:

PP Quality Flags (bit setting in TM Parameter "QUAL")	
Flag	**Meaning**
1	At least one sample = 255 in current (transmitter) time series
2	At least one sample = 0 in current (transmitter) time series
4	At least one sample = 255 in voltage (receiver) time series
8	At least one sample = 0 in voltage (receiver) time series

5.5 Common Actions and Control of Command Processing

IDENT	Com-mand Word	Parameter Words			Description
		No	Meaning	Valid Range	
COM_HK	7200	n/a	n/a	n/a	SESAME Health Check
COM_WDLY	7501	1.	Waiting period [s]	0001..FFFF	Subsequent telecommand shall be executed after a pause of "waiting period" seconds
COM_WLOBT	7603	1.	LOBT low word	0001..FFFF	Subsequent telecommand shall be executed not before the given LOBT.
		2.	LOBT midth word	0001..FFFF	
		3.	LOBT highest (5) bits	0000..001F	
COM_RBUF	7A02	1.	Unit	Valid subsystem address of a unit	Read record of Backup RAM Buffer of unit "unit" starting at "offset"
		2.	Offset	Valid offset in units Backup RAM Buffer	
COM_RDJC	7B01	1.	Offset	Valid offset in SESAME STC buffer	Read Stored TC record and store it to CASSE jobcard JOB_MES
COM_SPEC	7C03	three parameters		Parameters depend on programmed code.	Special command for debugging (used for H/W and S/W tests only). Functionality depends on test item.

5.5.1 SESAME Health Check (COM_HK)

All SESAME HK parameters are measured or collected and values are included into the SD stream. CASSE analogue power (± 5 V) is switched on during the execution of the command to allow the reading of the RadFET offset voltage on CASSE PCB. The RadFET offset voltage is measured twice, before and after a one-minute waiting period. The second reading shall deliver an additional dose signal after charge and discharge processes in the Si/SiO_2 border of the MOSFET are settled. The waiting period is used to execute particular measurements of the CASSE temperature channels and some reference voltage channels. The data obtained using dedicated A/D conversion routines allow the determination of temperatures lower than those covered by regular temperature measurements. Regular HK scaling and interpretation of measured values apply.

Expected SD Output for COM_HK Telecommand				
Item No.	**Byte No.**	**Meaning**	**(Typical) Value (hex)**	**Remarks**
1	0 to 13	SD Header	BCDE BCDE 7200 0000 0096 tttt tttt	Total length = 0x96 = 150 byte; last two words are SESAME Local Time
2	14, 15	UFPG		HK parameter: 3.3V (FPGA)
3	16, 17	UD+5		HK parameter: +5V (DIM)
4	18, 19	UD-5		HK parameter: -5V (DIM)
5	20, 21	UP+5		HK parameter: +5V (PP)
6	22, 23	U+05		HK parameter: +5V (CE)
7	24, 25	U-05		HK parameter: -5V (CE)
8	26, 27	U+12		HK parameter: +12V (CE)
9	28, 29	U-12		HK parameter: -12V (CE)
10	30, 31	U+28		HK parameter: +28V (CE)
11	32, 33	UCDP		HK parameter: +5V (C-DPU)
12	34, 35	URAD		HK parameter: Total Dose (RADFET)
13	36, 37	I+05		HK parameter: Current +5V (CE)
14	38, 39	I-05		HK parameter: Current –5V (CE)
15	40, 41	I+12		HK parameter: Current +12V (CE)
16	42, 43	I-12		HK parameter: Current -12V (CE)
17	44, 45	I+28		HK parameter: Current +28V (CE)
18	46, 47	CEID	0xB5E5	HK parameter: SESAME ID
19	48, 49	TPCB		HK parameter: CASSE Board Temperature
20	50, 51	CLTC		HK parameter: Last Telecommand received
21	52, 53	CBTC		HK parameter: Last but one Telecommand
22	54, 55	LMID		HK parameter: SESAME Local Time (high word)
23	56, 57	LLOW		HK parameter: SESAME Local Time (low word)
24	58, 59	TT-Y		HK parameter: Foot –Y / TRM Temperature
25	60, 61	TA-Y		HK parameter: Foot –Y / ACC Temperature
26	62, 63	TT+X		HK parameter: Foot +X / TRM Temperature
27	64, 65	TA+X		HK parameter: Foot +X / ACC Temperature
28	66, 67	TT+Y		HK parameter: Foot +Y / TRM Temperature
29	68, 69	TA+Y		HK parameter: Foot +Y / ACC Temperature
30	70, 71	PPD		HK parameter: Electron Density
31	72, 73	SUPS		HK parameter: SRAM Usage/Power Status
32	74, 75	TIBO		HK parameter: Time since Boot [s]
33	76, 77	ERRF		HK parameter: Error Flags
The next item (no. 34) appears for each temperature channel, i.e. seven times. The order of temperature channels is foot –Y/TRM, foot –Y/ACC, foot +X/TRM, foot +X/ACC, foot +Y/TRM, foot +Y/ACC, CASSE PCB temperature.				
34	78 to 147	Data Block: Extended Temperature Measurement (see separate table)		

35	148, 149	URAD-2		Second measurement of RadFET offset voltage.

Data Block: Extended Temperature Measurement				
Item No.	**Byte No.**	**Meaning**	**(Typical) Value (hex.)**	**Remarks**
1	0, 1	T-HK		Voltage of temperature channel using regular HK measurement; should be practically equal to the value of the corresponding HK parameter.
2	2, 3	T-I1		Intermediate voltage measured shortly after switching from temperature channel to reference channel 1.
3	4, 5	T-R1		Voltage of reference channel 1 = UCDP.
4	6, 7	T-I2		Intermediate voltage measured shortly after switching from temperature channel to reference channel 2.
5	8, 9	T-R2		Voltage of reference channel 2 = U+28.

5.5.2 TC processing: Pause (COM_WDLY)

The processing of incoming telecommands is stopped for the period specified in the parameter word.
No science data are generated.

5.5.3 TC Processing: Wait until Lander Onboard Time (COM_WLOBT)

The processing of incoming telecommands is stopped until Lander Onboard Time specified in the parameter words.
No science data are generated.

5.5.4 Read Backup RAM Buffer (COM_RBUF)

This command is used to check whether access to Backup RAM Buffer works and to verify the contents of a Backup RAM Buffer record. One record of a unit's Backup RAM Buffer in CDMS memory is read and the contents included in the telemetry stream. The unit is specified by the subsystem address (cf. CDMS Subsystem Specification) and can be SESAME itself. The expected content of specific records in the Backup RAM Buffer of some units was laid down in the interaction document (RO-LSE-TN-3403).

Expected SD output for Read Backup RAM Buffer (COM_RBUF)			
Byte No.	**Meaning**	**(Typical) Value (hex.)**	**Remarks**
0 to 13	SD header	BCDE BCDE 7A02 0000 0052 tttt tttt	Total length: 0x52 = 82 byte; last two words are SESAME Local Time
14, 15	Unit Subsystem Address		Echoed command parameter
16, 17	Offset in Backup RAM Buffer		Echoed command parameter
18 to 81	Contents of Backup RAM Buffer Record		Record is copied byte by byte to TM stream

5.5.5 Read Jobcard from Stored TC Buffer (COM_RDJC)

This command is used to check whether access to Stored TC Buffer works and to demonstrate an alternative way of commanding the CASSE instrument. The TC is used for ground tests and should be applied with care because of the side effect (writing to the CAS_MES jobcard). One record of SESAME STC buffer in CDMS memory is read and the first 16 words of that record (length of a jobcard) included in the telemetry stream. Additionally these words are copied to the CASSE JOB_MES jobcard in SESAME RAM. Subsequent CASSE measurements commanded by telecommand CAS_MES are controlled by that jobcard, thus it should be ensured that the STC record contains a valid CASSE jobcard, if such measurements are intended without a preceding CAS_RDJC command.

Expected SD output for Read Stored TC Buffer (COM_RDJC)			
Byte No.	**Meaning**	**(Typical) Value (hex.)**	**Remarks**
0 to 13	SD header	BCDE BCDE 7B01 0000 0030 tttt tttt	Total length: 0x30 = 48 byte; last two words are SESAME Local Time
14, 15	Offset in STC Buffer		Echoed command parameter
16 to 47	First 16 Words of STC Record		Record is copied byte by byte to TM stream

5.6 Special Messages in Science Data Stream

5.6.1 Ready Message

After boot, SESAME S/W performs some basic initialization, transmits a Send Service System Status (SSST) request to CDMS, and waits two seconds. With CDMS running in normal mode, SESAME should receive at least one CDMS RTIM (Receive Onboard Time) message during the waiting period and the timestamp in the SD header of the Ready Message should than be adjusted to LOBT (showing SESAME Local Time approximately two seconds after boot). SESAME software does not wait for the requested RSST message from CDMS. If no RSST message has been received during the two seconds period, the fields of the RSST command words are filled with “0000”.

SESAME Ready Message				
Byte No.	**Type**	**Meaning**	**Value (hex.)**	**Remarks**
0 to 13	SD header		BCDE BCDE 0000 0000 0052 tttt tttt	Total length: 0x52 = 82 byte; last two words are SESAME Local Time
14 to 39	String*26		5345 5341 4D45 2046 6C69 6768 7420 532F 5720 202D 2052 6561 6479	Character representation: "SESAME Flight S/W - Ready"
40 to 45	3*UW	n/a	0000 0000 0000	
46 to 53	String*8	Flight S/W version		Contains the S/W version, padded with trailing blanks if necessary (e.g. “FM2.00 “)
54 to 61	4*UW	n/a	0000 0000 0000 0000	
62 to 81	10*UW	1st to 10th command word of CDMS RSST message		Cf. CDMS specification (RO-LCD-SP-3101) for meaning and data type.

5.6.2 Error Messages

Science Data with measurement id 0x7F00 are error messages. Error messages contain the string "Error Message" followed by one or more error codes.

SESAME Error Message			
Byte No.	**Meaning**	**Typical Value (hex.)**	**Remarks**
0 to 13	SD header	BCDE BCDE 7F00 llll llll tttt tttt	lll lll is total length, depending on number of error code words contained; last two words are SESAME Local Time
14 to 27	Identifying character string	4572 726F 7220 4D65 7373 6167 6520	character representation: "Error Message "
one to eight error code words follow; for each error code word:			
+1 to +2	Error Code Word		

Error code words are constructed in the following way:

Error Code Word Bit Structure															
15	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
Error Level				**Subsystem/Module**				**Error Number**							

Error Level:
- 0x0: Information for debugging, no error
- 0x1: Warning
- 0xE: Error
- 0xF: Fatal Error, Reboot required

Subsystem:
- 0x0: Global routines
- 0x1: ADC, HK
- 0x4: CDMS I/F
- 0x5: Science data processing
- 0x6: Telecommand processing
- 0xA: CASSE S/W
- 0xB: DIM S/W
- 0xC: PP S/W
- 0xD: Common actions

Error number:
Unique number within subsystem numbering.

Some potential error conditions, which were expressed by error messages in former software versions, are now indicated in HK parameter ERRF. The following error codes for error messages are used further on in error messages.

Error Codes in Error Messages			
Error Code	**Sub-system**	**Source File**	**Meaning**
1601	TC process.	TC.4TH	Unknown command category, TC ignored.
1617	Common	CDPU.4TH	Unknown common TC.
1A01	CASSE	CASSE_FM.4TH	Wrong temperature channel, set to default (1).
1A11	CASSE	CASSE_FM.4TH	Unknown CASSE TC.
1B01	DIM	DIM.4TH	Invalid margin, set margin to 0.
1B02	DIM	DIM.4TH	Invalid direction, set direction to X.
1D03	Common	CDPU.4TH	Could not allocate memory (COM_HK).
1D08	Common	CDPU.4TH	Error reading Backup RAM Buffer.
1D09	Common	CDPU.4TH	Error reading Stored TC Buffer.
E106	Common	CDPU.4TH	Could not allocate memory (COM_RBUF).
EA20	CASSE	CASSE_FM.4TH	Could not allocate memory (CAS_HC).
EA22	CASSE	CASSE_FM.4TH	Could not submit measurement (CAS_HC).
EA24	CASSE	CASSE_FM.4TH	Could not allocate memory (CAS_MES).
EA26	CASSE	CASSE_FM.4TH	Could not submit SD (CAS_MES).
EAFF	CASSE	CASSE_FM.4TH	Allocated memory space exhausted.
EB20	DIM	DIM.4TH	Could not allocate memory (DIM_CA).
EB21	DIM	DIM.4TH	Could not submit SD (DIM_CA)
EB22	DIM	DIM.4TH	Could not allocate memory (DIM_NT).
EB23	DIM	DIM.4TH	Could not submit SD (DIM_NT)
EB24	DIM	DIM.4TH	Could not allocate memory (DIM_ST).
EB25	DIM	DIM.4TH	Could not submit SD (DIM_ST)
EB26	DIM	DIM.4TH	Could not allocate memory (DIM_PC).
EB27	DIM	DIM.4TH	Could not submit SD (DIM_PC)
EB28	DIM	DIM.4TH	Survey: Bad instrument health.
EB2A	DIM	DIM.4TH	Could not allocate memory (DIM_AV).
EB2B	DIM	DIM.4TH	Could not submit SD (DIM_AV, DIM_AV)
EB2C	DIM	DIM.4TH	Could not allocate memory (DIM_BC, DIM_BCTEST).
EB2D	DIM	DIM.4TH	Could not submit SD (DIM_BC, DIM_BCTEST)
EB2E	DIM	DIM.4TH	Autonomous Mode: Computed measurement duration for one AV- or BC measurement derived from total measurement duration (TC parameter) is too small.
EB2F	DIM	DIM.4TH	Autonomous Mode: Bad instrument health.
EB31	DIM	DIM.4TH	Survey: Allocated SRAM memory exhausted.
EB32	DIM	DIM.4TH	Survey: Excessive overcurrent interrupts.
EBF1	DIM	DIM.4TH	Unknown DIM TC.
EC30	PP	PP.4TH	Could not allocate memory (PP_HC).
EC31	PP	PP.4TH	Could not submit SD (PP_HC).

Error Codes in Error Messages			
EC32	PP	PP.4TH	Could not allocate memory (PP_DA).
EC33	PP	PP.4TH	Could not submit SD (PP_DA).
EC52	PP	PP.4TH	Could not allocate memory (PP_LM).
EC53	PP	PP.4TH	Could not submit SD (PP_LM).
EC54	PP	PP.4TH	Could not allocate memory (PP_AM2).
EC55	PP	PP.4TH	Could not submit SD (PP_AM2).
EC57	PP	PP.4TH	Could not allocate memory (PP_AMTEST2).
EC58	PP	PP.4TH	Could not submit SD (PP_AMTEST2).
EC5C	PP	PP.4TH	Could not allocate memory (PP_PM2).
EC5D	PP	PP.4TH	Could not submit SD (PP_PM2).
EC5E	PP	PP.4TH	Could not allocate memory (PP_PMTEST2).
EC5F	PP	PP.4TH	Could not submit SD (PP_PMTEST2).
ECE1	PP	PP.4TH	Unknown PP TC.
ED04	Common	CDPU.4TH	Could not submit SD (COM_HK).
ED05	Common	CDPU.4TH	Could not submit SD (COM_RBUF).
ED07	Common	CDPU.4TH	Timeout during Backup Buffer RAM reading..
ED0A	Common	CDPU.4TH	Timeout during Stored TC Buffer reading..
ED0B	Common	CDPU.4TH	Could not allocate memory (COM_RDJC).
ED0C	Common	CDPU.4TH	Could not submit SD (COM_RDJC).

6 Software Release Notes FM 2.0

6.1 General

Current software release is version FM-2.0. The software was uploaded to the Philae GRM and accepted for use in flight on 9. May 2007 (cf. H.-H. Fischer, K. Seidensticker, “Test of SESAME PC #6 preparation with the Philae GRM (9. May 2007)”, 14. May 2007). The upload to the SESAME FM took place during Philae payload checkout #6 in September 2007 (cf. Philae Payload Checkout 6 (SESAME Cruise Phase Report), RO-LSE-RP-3102, issue PC6).

Release FM-2.0 represents a major step towards the final flight software version, which is required for all operations near and on the comet. DIM autonomous mode was implemented and only minor improvements are currently open concerning the DIM software. An optimized PP measuring strategy was implemented and onboard evaluation of PP active and passive mode data was added; currently, no further extensions of the PP software are planned. CASSE measuring possibilities were extended with the triggered mode. The development of dedicated CASSE on-comet operation modes and operation autonomy will be a major item for the next software release.

Due to modified or extended instrument modes, revised science data processing and improved HK content the telemetry formats had to be modified to a larger extend. The major differences compared to software release FM-1.0 are listed in chapter 6.2.5.

The Forth source code is now stored in text files and compiled to the RTX2010 target using LMI metacompiler version 4.2.

6.2 Implementation Status of User Requirements, Test Status and Caveats

6.2.1 Common Software Parts

Flight Software version 2.0 fulfils the global user requirements listed in RO-LSE-RD-3401 with the following exceptions:

UR-Id.	Description	Prior	Comments
GEN-02	The software shall be qualified and accepted within a flight representative hardware /software environment (S/W verification test-bed)	E	Not all parts of the S/W could be sufficiently tested with FM compatible electronics and sensors.
GEN-07	The software shall support program update via telecommand.	E	Use C-DPU Debug Monitor.
GEN-07.1	The software shall allow the update of operational parameters by telecommand.	E	Use C-DPU Debug Monitor.
GEN-09	The software shall run in two different operation modes: 1) Main Science Operations Mode, 2) Low Power Mode (reduced SESAME processor clock rate).	E	Low Power Mode of SESAME C-DPU has been disabled by H/W means.

UR-Id.	Description	Prior	Comments
GEN-11	The software shall provide optional science data compression.	V	Compression algorithm has been implemented but not yet connected to Flight S/W.
GEN-14	The software shall process science data with at most 64 kB data per measurement. **Constraint.**	E	Data volumes larger than 64 kB per measurement are possible.

The **memory allocation** scheme for science data and temporary measurement data was completely revised. The size of a single measurement is now limited by the available memory space in SESAME SRAM only and can thus exceed the limit proposed in the user requirements document (64 kB; cf. user requirement GEN-14 in RO-LSE-RD-3401).

The software **interface to CDMS** was improved including: (a) a more robust reaction on CDMS error messages and CDMS errors takes place. This addresses particularly the problem that science data transfer to CDMS stopped as a result of a previous Lander link break event. (b) A forced flush of science data was implemented after the completion of a measurement. This solves the problem, that sometimes the final science data were not transferred to ground with FM-1.0. The improved features were tested with the Philae GRM (cf. the report on the GRM test of 9. May 2007).

The **housekeeping** measurement procedure was improved. HK measurements now take place as often as actually needed and not – as with FM-1.0 – every two seconds during idle periods. HK measurements take place between instruments operations and are additionally enabled during certain waiting periods, while an instrument is operating. Housekeeping parameters now include time stamps and additional information on the operating status (extended error flags, SRAM usage, instruments power status).

In SESAME Health Check (COM_HK) the **RadFET dose signal** is now read twice, immediately after CASSE analogue power on and after a proper build-up of charge states in the MOSFET.

A method was developed and implemented, which shall allow the **measurement of (foot) temperatures** below the limit of the regular temperature measurements.

6.2.2 CASSE Control Software

Besides the new Triggered Mode the CASSE part of flight S/W is basically unchanged compared to version FM-1.0. However, some modifications were necessary to adapt to the new science data processing and memory management (e.g. larger data volumes are possible). Basis of S/W development was again the CASSE Software Description (RO-LSE-SP-3420), Issue 3, 15. June 2000. Some modifications were approved by CASSE group (M. Kretschmer). A draft version of issue 4 of the CASSE S/W Description has been comprehensively commented by S/W group ("Anmerkungen zur CASSE S/W Description Issue 4", 04.Feb. 2001, H.-H. Fischer). The CASSE S/W user requirements document is out-of-date and shall be extended by the definition of autonomous on comet operations.

The beta version of flight software FM-2.0 included a work-around (additional H/W reset) for a property of the CASSE FPGA program, which sometimes complicates the assignment of time series to physical sensor channels. An unwanted side-effect of that work-around was observed during the Philae GRM test of the beta version (non-constant channel offsets). Although a further work-around could be found, which suppresses the side-effect, we decided to discard the work-around concerning the assignment problem in the final release FM-2.0.

The current implementation of CASSE power switching via telecommand CAS_PWRSW includes a waiting period after power on to allow sensor warm-up. Without this delay CAS_PWRSW could be used in advance of a CASSE measurement to switch on sensor power and use the period until sensors are ready for measurements of other instruments. However, it has to be ensured that no CASSE measurement (using sensors) is executed until the warm-up period has expired and powering of all CASSE circuits does not affect the measurements of other SESAME instruments.

6.2.3 DIM Control Software

Basis for the DIM part of flight S/W was the “DIM Software Description” (RO-LSE-SP-3440), issue 4, 25. January 2001. Details of the user requirements have been corrected and fixed in “Clarification of DIM Software User Requirements – Addendum to RO-LSE-SP-3440”. Currently a draft version of this document is available (draft 4, 24. July 2007).

With the completion of the autonomously measuring module all defined measuring modes have been implemented (some additionally in a test version with extended SD output) and may be commanded. However, during the entire S/W development it was not possible to perform an end-to-end test of the rather complex autonomous decision making (Which sensor faces are usable? Which data acquisition mode and which measuring parameters shall be applied?) due to missing electronics parts (the Philae GRM electronics was complete and available, but it provides only one case: All sensor faces OK and no dust impacts). Thus the Autonomous Mode is hitherto not released for flight operations. Likewise Average Continuous Mode could never be tested, while Burst Continuous Mode could partly be tested using software simulated impacts. Some minor code improvements (mentioned in the addendum to RO-LSE-3440 and in chapter 6.3) are open.

DIM Autonomous Mode will be released for regular flight operation after it could sufficiently be tested (with complete DIM laboratory equipment).

6.2.4 PP Control Software

Basis for the PP part of flight software was the PP Software Specification (RO-LSE-SP-3460), issue 2a, 8. September 2004. Deviations from the specification are described in “Flight Software FM-2 – PP Basic Algorithms and Software Test” (RO-LSE-TR-3460). The data acquisition strategy in PP Active and Passive mode was optimized for the onboard data evaluation. The major measuring modes are available with regular functionality (only the results of onboard data evaluation are sent to ground) and additionally with extended telemetry including raw data (transmitter and receiver time series).

PP FM-2.0 software was rather comprehensively tested. Results are documented in RO-LSE-RP-3460.

6.2.5 Overview of Telemetry Format Changes compared to FM-1.0

6.2.5.1 Science Data Telemetry

The header of each measurement data (**Science Data Measurement Header**) has been extended by one word to allow data volumes larger than 64 kB.

The meaning of bit settings in the **Science Data Packet Header** was slightly changed.

The **SESAME Ready Message** (boot message) now contains the flight software version and the Lander status as provided by a CDMS RSST message.

SESAME Health Check data (COM_HK) contain the new set of HK parameter data. The order of HK parameters is now according to the HK format count. Data used for the determination of low (foot) temperatures and a second reading of the RadFET voltage were added.

CASSE Triggered Mode data are considered by a branch (Triggered Mode *or* Burst Mode data) in the general CASSE TM format.

The size of the DIM (U,T)-matrix in **DIM Burst Continuous Mode** data is smaller now. The rest of DIM telemetry is essentially unchanged apart from the measurement header and slightly modified error flags.

All **PP formats** related to active and passive mode data are almost completely modified and extended.

6.2.5.2 Housekeeping Telemetry

Basically, a SESAME HK record holds the same information as with FM-1 (including the same scaling of analogue values). But the HK parameter set of 32 words was extended by substituting two parameters, which were included twice in FM-1 software and the content of some parameters was improved. In detail:

- Absolute and relative timestamps were included, which denote the measuring point in time of the HK values of the record.
- Information on the nominal electrical status of instruments (contents of CASSE, DIM, and PP power registers) was added (this allows the correct interpretation of voltage and current HK parameters).
- Further information is added: memory consumption, additional error codes (substituting – some – error messages in SD stream).
- The second occurrence of CE-U1 and CE-U2 is removed (substituted by midst and low word of LOBT timestamp).
- The structure and contents of the (former) software-flags (CE-F1 to CE-F3) was revised.
- Because time information is included in the HK parameter set, there is no need for “new”/”old” flags and they do not exist anymore.
- The HK source and version identifier CEID was changed to 0xB5E5.

6.2.6 Known Problems

The **reading of a Backup RAM Buffer record** (command COM_RBUF) does not deliver the recent contents but the contents read with an earlier COM_RBUF command in case a CDMS error flag is set in the SESAME HK parameter ERRF. This was recognized during the Philae GRM test of flight procedure “SD-2 L” (cf. test report of 4. July 2007). During SD2-L, SESAME received the CDMS error message "Mass memory full" shortly before the execution of the second COM_RBUF. The appropriate error flag was set in HK parameter ERRF. After sending the request for the SD2 Backup RAM record flight SESAME software did not wait for the arrival of the Backup RAM record, because a CDMS error flag was set. This flag was cleared later after the content of ERRF was delivered to CDMS during regular housekeeping. The next version of the SESAME flight software shall include a more precise checking of the CDMS error flags. Additionally, the telemetry of command COM_RBUF shall include an error code word, which indicates the successful / not successful execution of the command.

The **PP error code word** is not cleared at the beginning of a PP active test mode measurement. Thus the error code of a particular PP_AMTEST or PP_AMTEST2 measurement might indicate an error, which actually occurred during a previous execution of the command.

6.3 Open Work (next software release)

Features & Activities for the next S/W Release		
Name	**Task**	**Comments**
CAS01	Autonomous measurements	
CAS02	Sample/Channel Shifts	Work-around implemented & tested in FM-2 Beta but finally discarded; unwanted side-effect recognized
CAS03	Sensor-Warmup-Time	Avoid Sensor-Warmup-Time for subsequent measurements (modify CAS_PWRSW and power switching)
CAS04	CAS-LIS: Averaging	Preparatory work done
CAS05	Data Compression	Compression algorithm implemented, but not connected to data flow
CAS06	Flight S/W -> Ground S/W	Some instrument settings are unnecessarily calculated by Flight S/W; can be calculated more flexible and safely by Ground S/W
CAS07	Jobcard parameters	Improve the jobcard structure and the data range of parameters (e.g. enable longer measurement duration).
CAS08	Interaction with other instruments	“MUPUS noise”, SD2, TBD
CAS09	Telemetry / error code	Include error code after initialisation in Burst Mode data.
DIM01	S/W according to User Requirements V4	
DIM01.1	Burst Continuous	Reduce Aver_Settle to 2 s
DIM01.2	Addendum to user requirements doc.	Almost final clarification of user requirements achieved in draft/4.

Features & Activities for the next S/W Release		
Name	**Task**	**Comments**
DIM02	Over-current interrupt	Proposed work-around to be approved by DIM group.
DIM03	DIM_BCTEST	Include timestamp for single impacts; consider a limitation for the number of impacts to record.
DIM04	Functional Test	Additional H/W required.
DIM04.1	Test of DIM Autonomous Mode	Possible after completion of laboratory equipment.
DIM04.2	End-to-end tests of all modes	Possible after completion of laboratory equipment.
DIM05	Signal Average	Consider to send average signal av[mV] to ground, not av[dB] and to remove calculation of and all references to av[dB].
DIM06	Number of events in BC	Enlarge data range of BC_NE, BC_NL, BC_NF by using 2VARIABLES.
DIM07	HK measurement during average measurement.	Consider the use of settling period during average signal measurement for collecting HK values.
PP01	Clear PP_ERR at start of PP_AMTEST and PP_AMTEST2	
COM01	Revise COM_RBUF	Faulty reading of BRAM record in case a CDMS error is indicated in HK parameter ERRF.
COM02	LMI Metacompiler 4.2	Check potential faulty op codes when compiling with version 4.2.
COM03	Use waiting periods for SD transfer.	Consider the use of long (>30 s) waiting periods during measurements for transferring data of a previous measurement.
MIS01	Facilitation of procedure tests.	Time-tagged sending of TCs with tkCDMS.
MIS02	Test of exemplary/worst case measurement scenarios.	

7 Appendix

7.1 Directory Structure of Software Sources and Documents

```
\ARCHIVE RELEASED VERSIONS
+--FM2_0
+--FLIGHT SOFTWARE
|  +--APP
|  |  +--APPLICAT.DEF                global unit settings
|  |  +--APPLICAT.4TH                global unit include file
|  |  \--SESAME.4TH                  SESAME include file
|  +--CTL
|  |  \--MAIN01.4TH                  main loop
|  +--GLB
|  |  +--ANALOG.4TH                  ADC, HK
|  |  +--ERRMSG.4TH                  error handling routines
|  |  +--MEMORY.4TH                  dynamic memory allocation
|  |  +--GLOBAL.4TH                  Forth core extensions, common data
|  |  \--TYPES.4TH                   data structures
|  +--IO
|  |  +--CDMSIF.4TH                  I/F to CDMS
|  |  +--SD.4TH                      SD processing
|  |  \--TC.4TH                      TC processing
|  +--MES
|  |  +--CASSE.4TH                   CASSE control S/W: include file
|  |  +--CASSE_EM.4TH                CASSE control S/W: version for EM PCB
|  |  +--CASSE_FM.4TH                CASSE control S/W: version for FM PCB
|  |  +--CDPU.4TH                    control of common actions
|  |  +--DIM.4TH                     DIM control S/W
|  |  +--PP.4TH                      PP control S/W
|  |  \--WinForth Testsources        test routines for DIM, PP software (WinForth)
|  +--OS
|  |  +--BIOS.4TH                    C-DPU BIOS
|  |  +--RTX20R4.4TH                 Forth core
|  |  +--RTXARI.4TH                  LMI arithmetic routines
|  |  +--RTXDIS.4TH                  LMI Forth disassembler
|  |  +--RTXFLOAT.4TH                LMI floating point arithmetic
|  |  +--RTXSTAT1.4TH                LMI optimizing compiler state tables
|  |  \--RTXTRACE.4TH                LMI debug routines
+--0RTX.BAT                          connection to C-DPU via serial I/F (LM)
+--MAKEFILE                          invokes metacompiler for all source files
+-\FM2_0.IMG                         SESAME Flight S/W program
+--AUXILIARY SOFTWARE                GUI tkCDMS (DLR-BA)
+--SD COMPRESSION
|  +--FLIGHT
|  |  \--COMPRESS.SCR                encoding algorithm
|  |  +  TEST                        test routines for encoding algorithm
|  +--GROUND                         decoding, tests
+--GROUND SOFTWARE
|  +--SRC
|  |  +--PARSE_SD.C                  parse TM packets (SD)
|  |  +--PARSE_HK.C                  parse TM packets (HK)
|  +--BIN
+--DOCUMENTATION
```