CENA
Software Interface Control Document

	Name and function	Date	Signature
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CHANGE RECORD

Version		Date	Changed Paragraphs	Remarks
Issue	Rev			
Draft	0	2005-03-22	All	New document
1	0	2005-04-08	Many	
1	1	2005-04-30	Sections 5, 6, 6.1, 8.5, 9, 10.1, 10.2.1, 10.2.2, 10.2.3 Figure 4 Tables 2, 5	
1	2	2005-08-18	Section 8.5	
1	3	2005-08-30	Sections 5, 6.1	
1	4	2005-11-04	Sections 6.2, 7, 8, 9, 10, 11, 13 Figures 5, 6, 7 Tables 4, 5, 6, 7	
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2	1	2006-02-15	Section 8.4	
2	2	2006-05-03	Section 7.4, 10.6, 11 Inserted section 10.7	
2	3	2006-05-17	Sections 8.5,8.6	
2	4	2006-06-14	Section 8.5	
2	5	2006-08-31	All	Editorial
2	6	2006-10-05	Sections 7.1, 10.12, 10.13, 10.6, 10.10	Editorial, clarifications, 32bit lin to log compression table
2	7	2006-11-20	Section 8.4 Figure 5, 8	Editorial changes
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3	3	2008-02-04	9.5	

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TABLE OF CONTENTS

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1 INTRODUCTION

This document defines the interaction between CENA sensor and the DPU as well as general requirements for onboard data processing software. The purpose of this document is to provide the DPU development team with a description of how the CENA sensor works and what is required from the DPU. The most important parts are section 7 which describes the data sent by the sensor to the DPU, section 8 which describe the commands to the sensor, section 9 which describes the telemetry commands the DPU needs to implement, section 10 which describe the DPU data processing and section 10.2 which describes the telemetry modes, and thus essentially describes what the DPU should transfer to the spacecraft telemetry system.

2 APPLICATION

This document shall form a base for the top-level design of the instrument package.

3 REFERENCE DOCUMENTS

RE1 CHA-SARA-DS-0002-IxRy (CENA Mass Accumulation Mode Lookup Tables).xls
RE2 CHA-SARA-DS-0005-IxRy (SWIM Software Interface Control Document).pdf
RE3 CHA-SARA-DS-0015-I0R0 (SARA HK Decoding).pdf
RE4 CHA-SARA-TR-0014-I0R1 (SAS Housekeeping Calibration Functions).pdf

4 DESCRIPTION

SARA consists of three separate units:

- CENA – Chandrayaan-1 Energetic Neutrals Analyser (IRF)
- SWM – Solar Wind Monitor (IRF)
- DPU – Digital Processing Unit (ISRO)

CENA and SWM are sensor units, which trough the DPU, are connected to the spacecraft. The DPU contains the processor, Experiment Interface Unit (EIU), Power Distribution Unit (PDU) and Spacecraft Interface Unit (SIU).

5 CENA DESIGN

The CENA sensor does not contain an on-board CPU and is thus dependent on the main DPU unit for all more advanced operations. The sensor consists of four subsystems, namely, a charged-particle rejection system (deflector), a conversion surface, an energy-analysis system (which also performs efficient photon rejection), and a detection system that provides mass (velocity) analysis. Figure 1shows the principle of CENA detection.

A neutral particle enters the sensor through the charged-particle rejection system, which rejects ambient charged particles with energies up to ~15 KeV by a static electric field. The incoming neutral particle is then positively ionized by hitting a conversion surface and is reflected toward an electric guide of a special shape.

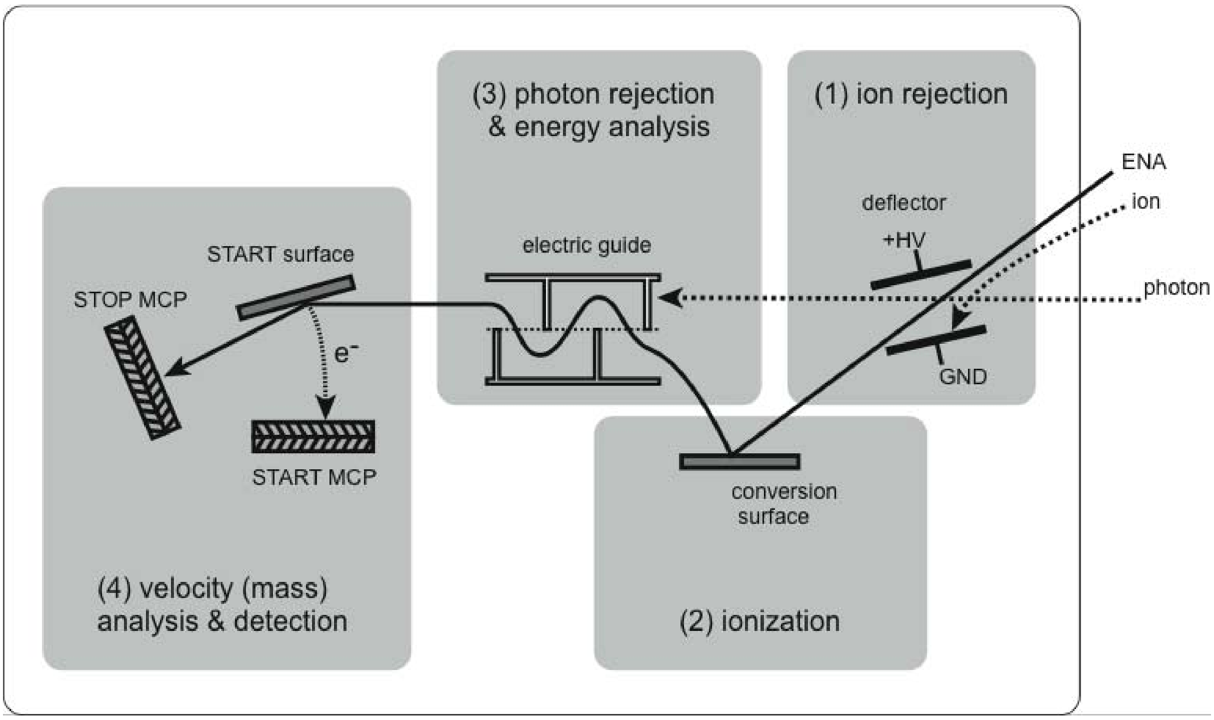


Figure 1 CENA block diagram

Figure 2 illustrates the field of view of the instrument divided into seven sectors which cover approximately 160 degrees in the azimuthal direction. In the electric guide, the ionized ENA moves along wave-like trajectories (wave-type analyzer), while photons are mostly absorbed in UV traps on the walls of the guide. The wave-type electrostatic guide also provides energy analysis. The concept of this guide design is similar to the one used in the MTOF sensor of the CELIAS instrument (Hovestadt et al., 1995) on the SOHO spacecraft, which provides a UV photon rejection factor of 2×10^{-8}.

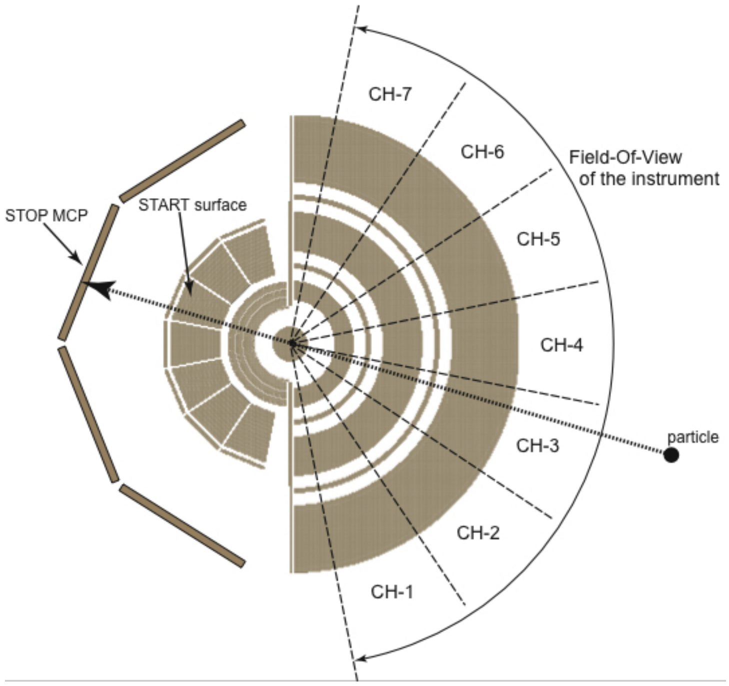


Figure 2 CENA FoV

Since the instrument must be capable of measuring heavy atoms with masses up to 56 (iron), no carbon foils can be used anywhere inside the sensor. Using foils requires post-acceleration by unrealistically high voltages (typically a particle velocity of 1 KeV/nucleus is needed).

In order to measure the particle velocity (mass), the particle reflection method developed for the Neutral Particle Detector (NPD) of the ASPERA-3 and ASPERA-4 experiments onboard ESA's Mars and Venus Express missions (Barabash et al., 2004) is used. After exiting the electric guide, the particle is postaccelerated by a voltage of ~3 kV before it impacts on the START surface. Upon particle impact, secondary electrons are emitted from the START surface, which are guided to the START micro-channel plates (MCPs) to produce a START pulse. The example of secondary electron trajectories is illustrated in Figure 3 with potential contours.

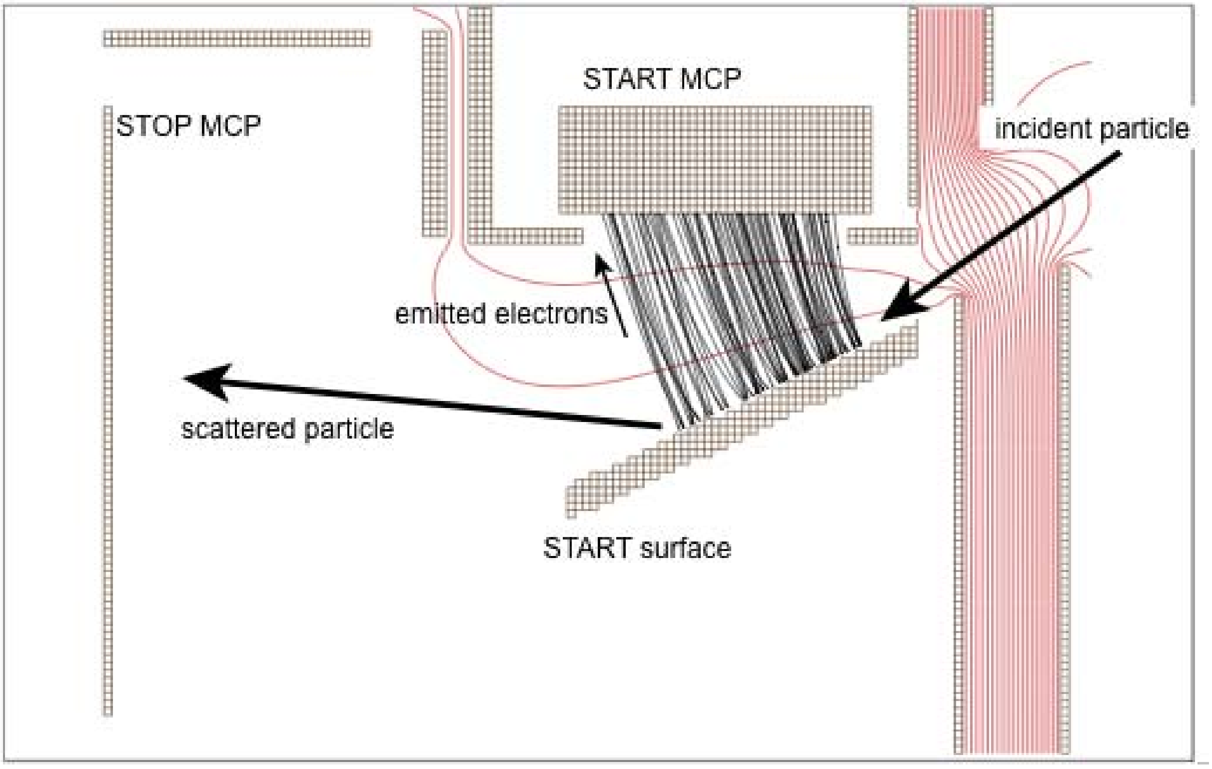


Figure 3 Secondary electron trajectories

The electrons are collected on the Start MCP by a small potential difference of 300 V. The START surface, START MCP, and the post-acceleration electrodes are carefully designed in order not to significantly affect trajectories of incident particles. The incident angle achieved is on average approximately 15 deg. The particle is reflected on the Start surface towards the STOP MCPs, where it is detected to produce a STOP pulse. The time-of-flight (TOF) between the START and STOP signals gives the particle velocity. Combining the TOF measurement and the energy analysis of the particle, the mass of the CENA particle can be determined.

The START MCP provides the two-dimensional position (in radius and azimuth) and the timing of the particle reflected on the START surface. The radial position allows accurate determination of the TOF length, and the azimuthal position provides the azimuthal angle of the incoming LENA.

The instrument was designed by performing a large number of computer simulations, not only to maximize each performance but also to balance between the priorities listed above. The main difficulty in designing the instrument is the balance between the mass resolution and large geometrical factor, while keeping sufficient angular resolution. The instrument is capable of resolving major species, such as H, O, Na, K, and Fe.

Summary of the performance of the CENA instrument.

Parameter	**Value**
Energy range	~10 – 3300 eV
Geometrical factor	~5 cm^2 sr eV/channel for 25 eV ~50 cm^2 sr eV/channel for 3300 eV
Total efficiency	1%
Angular resolution	9 deg × 30 deg
Field of view	20 deg × 157 deg for 25 eV 20 deg × 130 deg for 3300 eV
Mass	2.0 kg
Power	2.3W (IFE) + TBD W (HVPS), no margin included
Envelope	224 mm × 207 mm × 87 mm

6 CENA OPERATION

6.1 Sensor operation

The energy of the incoming particles is determined by TOF values and high voltages (SV_Wave1, SV_Wave2A, SV_Wave2B, and SV_Lens) which are applied to the electrodes in the sensor. These high voltages are automatically changed by the CENA interface electronics (IFE) according to tables stored in RAM. The DPU has to write the tables before the measurement starts, which means that the DPU knows the output level of high voltages at any time.

The Start MCP stack consists of two plates. Behind the Start MCP stack there are two types of anodes. The position sensing anode consists of 4 rings and 7 sectors, e g 11 Start anodes. The timing anode (Start pulse) consists of 7 sectors which are electrically connected together. Each of the four Stop MCP stacks consists of three plates. Behind each Stop MCP stack there are two types of anodes. One is the Stop sector anodes , e g 8 Stop sector anodes. The other is a Mesh anode located between MCP output surface and the Stop sector anodes. There are four Mesh anodes but they are all electrically connected together. Channel definition of each anode is shown in
Figure 4. The signal from the Start pulse and the Stop pulse meshes are amplified and supplied to a TDC (Time to Digital Converter). If coincidence is detected, the TDC provides a TOF value. Following energy analysis, an energy level is provided by the sensor's electronics.

In general, CENA include anode channels (Start ring, Start sector and Stop sector) to which particles will hit and which will provide directional information. The energy steps can be recognized by the data format since the data is sorted by energy steps. Thus, the DPU can determine mass, energy, and incoming direction of particles. It is foreseen that the DPU makes binning of data according to look-up-tables which will be rewritable by commands from ground. It is also foreseen that the DPU can send the data without binning, which is useful when the detected count rate is low.

The CENA sensor has several instrumental modes such as Coincidence mode, Counter mode, and Engineering mode. Description of each mode is described in section 0 The modes are possible to be changed by commands from the DPU.

In order to start the measurement, initialization and settings are necessary for the CENA sensor (Section 8.4).

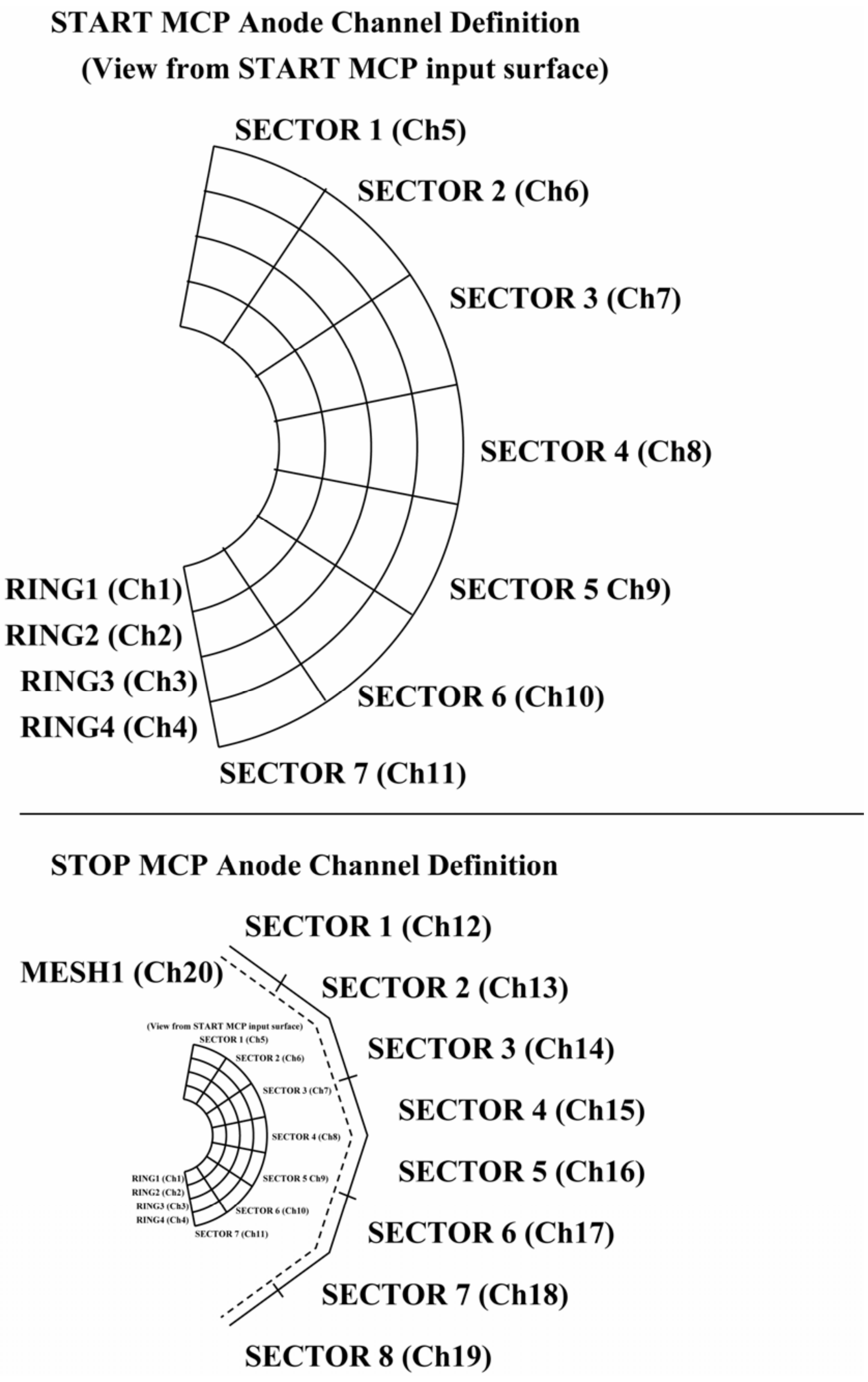


Figure 4 Channel definition

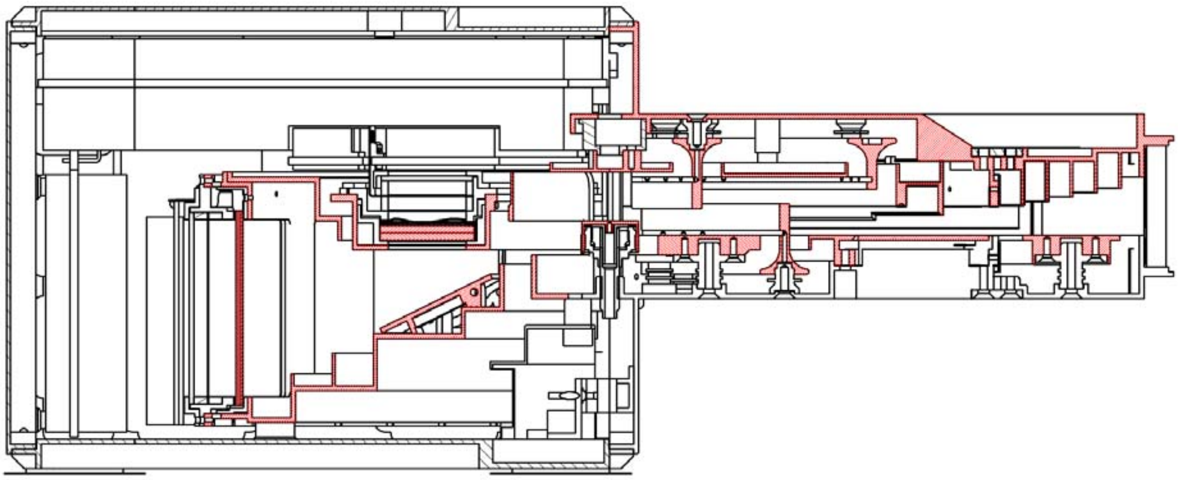


Figure 5 CENA cross-section

6.2 Command and data flow

The data and command flow specification in this document is divided into two parts:

a) **Definitions** of sensor data and commands exchanged between CENA and DPU (sections 7 and 8).
b) **Requirements** for functionality on the DPU (sections 9 and 10), which includes the description of the data to be sent to S/C and functionality needed in telemetry commands to the DPU

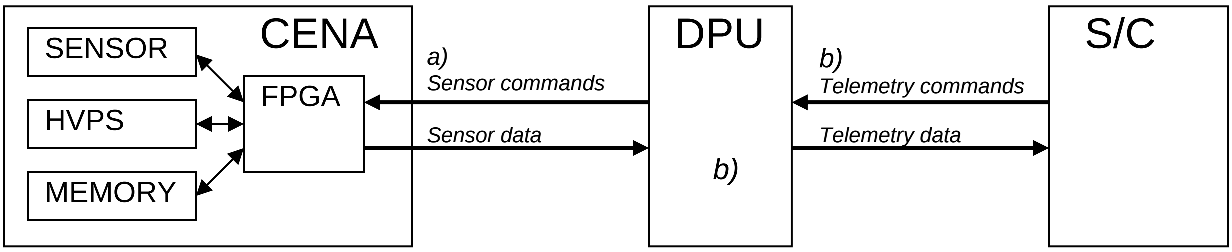


Figure 6 Command and data flow

7 SENSOR DATA STREAM

7.1 Timing and synchronisation

The energy sweeping (different HV setting) is made by the sensor itself and synchronised to an internal clock that is syncronized with the Sync pulse. One cycle for energy sweeping contains 8 energy steps. The duration of one cycle is fixed to 250 msec, which means that one energy step is always 31.25 msec.

This value is derived by the interval of the Sync pulse which has to be supplied by DPU (1pulse / 4 seconds), i.e., in the CENA sensor, one energy step is always calculated to be 1/128th of appearance interval of last two Sync pulses.

Slot counts the 31.25ms intervals starting with 0 at a clock pulse. Energy step and Phase are calculated out of Slot number by:

Energy step = Slot modulo 8
Phase = Slot / 4

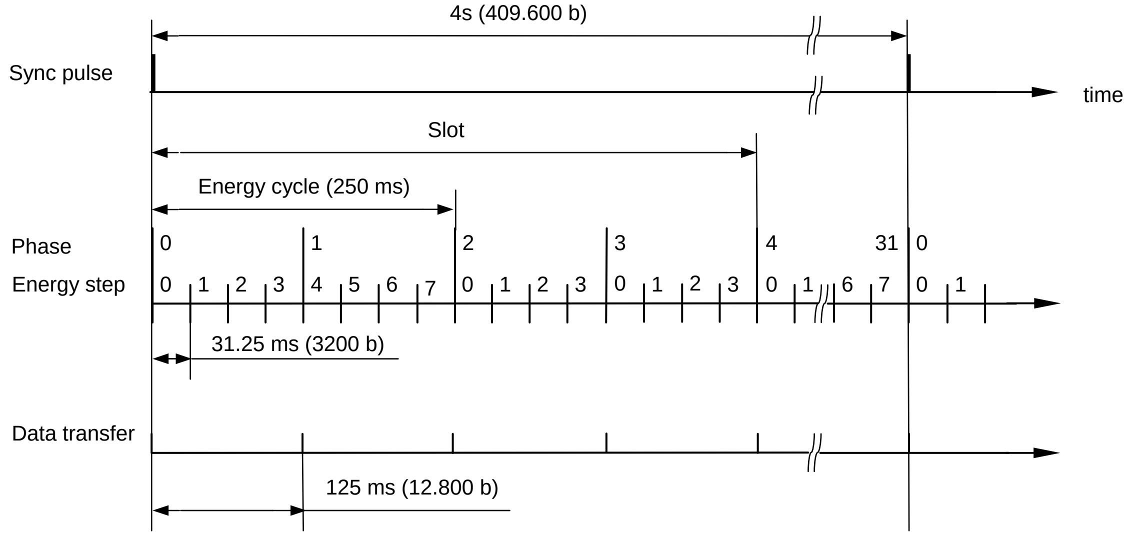


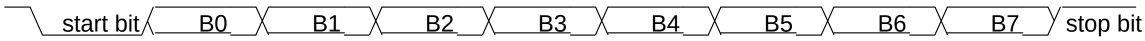
Figure 7 CENA timing

The sensor accumulates data in a memory in the sensor and the data is sent to the DPU every half energy-sweep cycle (125 msec). The data transfer is initiated by the sensor and does not require any DPU commanding of the sensor. The average net data rate between the sensor and DPU is 100 kbps.

The data from the sensor contains 4 data sets, where each corresponds to one of the 8 energy steps. When the data from the sensor contain the data set of energy steps 0 to 3, the next data from the sensor correspond to energy steps 4 to 7. The data set for each energy step occupies 3200 bits, which gives a total bit rate of 3200 bit * 0.5 * 8 steps / 125 msec = 100 kbps. The total amount of data for 4 energy steps is 12800 bits (8 energy steps, 25.600 bits). No start and stop bits are included in the calculation of the bit rate. The maximum bit rate in the interface is 2 Mbps.

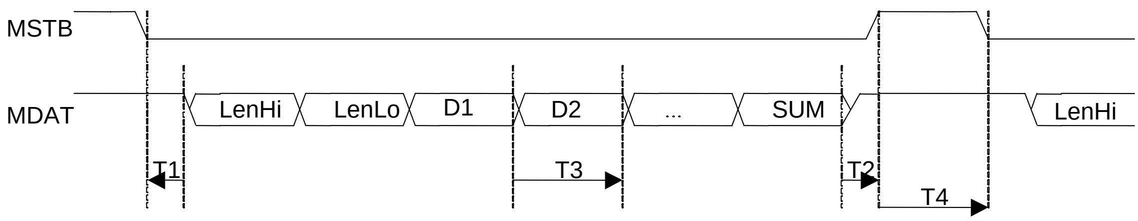
Some of the commands listed in Section 8.5 result in a extra data packet sent to the DPU. These packets are sent in between possible science packets described in Section 0.

7.2 Frame format



Start bit	active low
Stop bit	logical high
Bit width	0.5us (typ, 2Mbps)

7.3 Packet format



T1	0us (min)	Time interval from MSTB=LOW to CL
T2	0 us (min)	Time interval from SUM to MSTB=HIGH
T3	5 us (typ)	Time interval of one frame
T4	0 us (min)	Time interval to the beginning of next packet
LenHi	Bits [15:8] of Length	
LenLo	Bits [7:0] of Length	
Dn	Data packet bytes, a sequence of DT1, DT2, DT3, DV1, DV2, …DVn	
Length	3 (number of DT) + N (number of DV) + (SUM) = 3 + N + 1	
SUM	(D1 + D2 + … + DN) xor 0xff	

MSTB is used to enable MDAT.
Upon reception, the correct SUM is verified by: D1 + D2 ... + DN + SUM = 0xff
Illegal checksum should be reported in HK. Data should be accepted by the DPU in all cases nevertheless.

The sensor creates a 3200 bit data packet every energy step (31.25ms) which is stored in the sensor memory. After collecting four packets, the sensor sends these packets in a burst to the DPU every 125ms. No further data storage takes place in the sensor after the burst of four packets The corresponding memory in the sensor is automatically cleared and overwritten with new data.

Each data packet has a 16-bit leading header which contains 8 bits Packet ID and 8 bits slot number. It is followed by 8 bits of HK data and then science data.

HK data is sub-commutated, which means that every data packet from the sensor contains one 8-bit HK word. HK words from consecutive data packets must be reassembled in a sequence to get the complete HK data packet. A new HK packet starts at after the 4 second Sync pulse. Note that the sub-commutated HK data does not need to be requested from the DPU. It is always contained in the data packets which are automatically sent from the sensor.

7.4 Sensor modes

The sensor operates in one of three modes, which is set by commanding from DPU.

- Coincidence Mode
- Counter Mode
- Engineering Mode

7.5 Packet types

The format of the data being sent to the DPU changes depending on sensor mode. The following packet ID identifies the type of data which is sent.

Packet ID Bits [7:0]	**Type of packet**
0000 0000	Coincidence mode packet, Table 2
0000 0001	Counter mode packet, Table 4
0000 0010	Engineering mode packet, Table 5
1000 0010	Engineering mode packet with HK sub channel byte replaced by filling byte (see Section 0). This is also the packet ID used within the sub commutated HK data.
1000 0011	SV Table data packet with HK sub channel replaced by filling byte (see Section 0)
Other	Unused

Table 1 Packet identifiers

Bit 7 indicates weather the packet contains valid HK information (Bit 7 = 0) or a filling byte (Bit 7 = 1).

7.6 Packet contents

The sensor data formats of the different sensor modes are shown in Table 2 to Table 5. The Format of the data sent to the DPU following a sensor command is shown in Section 0.

7.6.1 Coincidence mode packet

Coincidence Mode	
No of bits	**Content**
8	packet ID, 00h
8	Slot bits [6:0]
8	Subcommutated HK data
16	Start counts
16	Stop counts
16	Coincidence Stop counts
20 * N	Coincidence Event Entry where N depends on count rate, (See Table 3)
Rest	Remaining space is filled with all zeroes (*)
3200	TOTAL

Table 2 Coincidence mode packet

(*) An entry consisting entirely of zeroes is considered an invalid entry and must be ignored.

Each event in coincidence mode consists of 20 bits with the following structure:

No of Bits	Content
3 b	Start ring ID
3 b	Start sector ID
4 b	Stop plate ID
10 b	TOF
20 b	TOTAL

Table 3 Coinc. Mode packet structure

Individual events are packed into bytes as shown in Table 6.

7.6.2 Counter mode packet

Counter Mode	
No of bits	**Content**
8	packet ID, 01h
8	Slot bits [6:0]
8	Subcommutated HK data
448	Start ring and sector count, 4 x 7 x 16b
64	Start ring count, 4 x 16b
112	Start sector count, 7 x 16 b
128	Stop plate count, 8 x 16b
16	Stop mesh count, 1 x 16b
112	Start sector coincidence count, 7 x 16b
20 * N	Coincidence and Non-coincidence event entry according to selection mask set where N depends on count rate, (See Table 3)
Rest	filled with zeroes (*)
3200	TOTAL

Table 4 Counter mode packet

(*) An entry consisting entirely zeroes is considered an invalid entry and must be ignored.

7.6.3 Engineering mode packet

Engineering Mode	
No of bits	**Content**
8	packet ID, 02h
8	Slot bits [6:0]
8	Subcommutated HK data
1000	Engineering data (all 125 DV elements from table Table 19)
Rest	filled with zeroes
3200	TOTAL

Table 5 Engineering mode packet

7.7 Event entries

Event entries are packed as dense as possible. The first entry in the event entry list starts at a byte boundary (bit B7), the second at bit B3, the third at a byte boundary (bit B7), and so on.

	B7	B6	B5	B4	B3	B2	B1	B0	Description
Dx	R2	R1	R0	S2	S1	S0	P3	P2	1st event: Start ring [R2:R0], Start sector [S2:S0]
Dx+1	P1	P0	T9	T8	T7	T6	T5	T4	Stop plate [P3:P0], TOF [T9:T0]
Dx+2	T3	T2	T1	T0	r2	r1	r0	s2	2nd event: Start ring [r2:r0]
Dx+3	s1	s0	p3	p2	p1	p0	t9	t8	Start sector [s2:s0], Stop plate [p3:p0]
Dx+4	t7	t6	t5	t4	t3	t2	t1	t0	TOF [t9:t0]
Dx+5	n	n	n	n	n	n	n	n	3rd event ...

Table 6 Event entries

7.8 Assignment of electrodes

TOF and positions at Start and Stop electrodes are assigned as follows.

Start ring number	Value stored in entry (3b)	START RING ID
START RING1	0x0	0
START RING2	0x1	1
START RING3	0x2	2
START RING4	0x3	3
invalid ring	0x4	undefined
invalid ring	0x5	undefined
invalid ring	0x6	undefined
No event on START RING	0x7	undefined / not applicable

Table 7 Start ring electrodes

Note that the number stored is START RING-number is -1 versus the definition in Figure 4. In contrast to the START RING number the stored value is referred as START RING ID for valid ring numbers. The ID is used as index in the lookup tables in Section 10.6. Any event containing invalid ring number (0x4 to 0x6) should be treated as if there was no event on START RING (0x7).

Start sector number	Value stored in entry (3b)	START SECTOR ID
START SECTOR1	0x0	0
START SECTOR2	0x1	1
START SECTOR3	0x2	2
START SECTOR4	0x3	3
START SECTOR5	0x4	4
START SECTOR6	0x5	5
START SECTOR7	0x6	6
No event on START SECTOR	0x7	undefined / not applicable

Table 8 Start sector electrodes

Note that the number stored is START SECTOR-number is -1 versus the definition in Figure 4. In contrast to the START SECTOR number the stored value is referred as START SECTOR ID. The ID is used as index in the lookup tables in Section 10.6.

Stop sector number	Value stored in entry (4b)	STOP PLATE ID
STOP SECTOR1	0x0	0
STOP SECTOR2	0x1	1
STOP SECTOR3	0x2	2
STOP SECTOR4	0x3	3
STOP SECTOR5	0x4	4
STOP SECTOR6	0x5	5
STOP SECTOR7	0x6	6
STOP SECTOR8	0x7	7
No event on STOP SECTOR	0xf	undefined / not applicable

Table 9 Stop sector electrodes

Note that the number stored is STOP PLATE-number is -1 versus the definition in Figure 4. In contrast to the STOP SECTOR number the stored value is referred as START SECTOR ID. The ID is used as index in the lookup tables in Section 10.6.

7.9 TOF data types

TOF data type	Value stored in entry (10b)
Invalid event	0x000
Valid event	0x001 …0x3ef
Spare for other "illegal event"	0x3f0 … 0x3fc
No event on STOP MESH and event on START SECTOR	0x3fd
No event on START SECTOR and event on STOP MESH	0x3fe
No event on START SECTOR and STOP MESH	0x3ff

Table 10 TOF data types

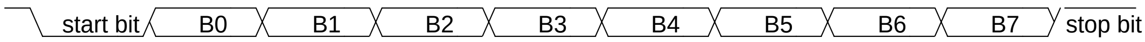
An entry consisting entirely of zero bits (0x00000) is considered an invalid entry and must be ignored.

8 CENA COMMANDS

8.1 Overview

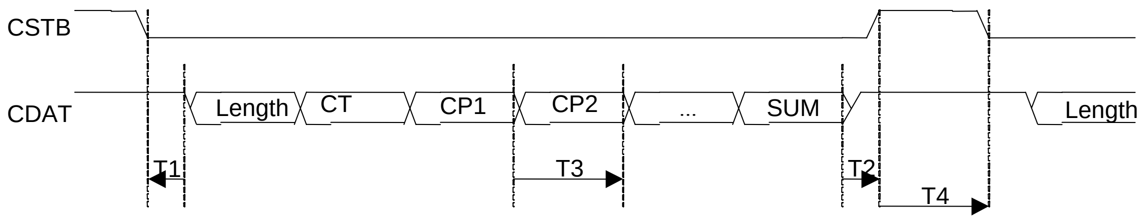
This section describes the single Sensor Commands that are sent from the DPU to the CENA sensor. Higher level functionality on the DPU that may result in sending Sensor Commands is described in section 9

8.2 Command frame format



Start bit: logical low
Stop bit: logical high
Bit width: 0.5us (typ 2Mbps)

8.3 Command packet format



T1	0 us (min)	Time interval from CSTB=LOW to CL
T2	0 us (min)	Time interval from SUM to CSTB=HIGH
T3	5 us (typ)	Time interval of one frame
T4	0 us (min)	Time interval to the beginning of next packet

CSTB is used to enable CDAT (CENA FPGA decodes CDAT data stream when CSTB is low). When more than one packet is sent continuously, CSTB does not have to be negated during the whole transmission.

CT	Command Type
Length	1 (Number of CT) + N (number of CP) + 1 (SUM) = 1+N+1
CP	Command Parameters
SUM	(CT + CP1 ... + CPN) xor 0xff

Upon reception, the correct SUM is verified by:
CT + CP1 ... + CPN + SUM = 0xff

Commands with illegal checksum will be ignored by the sensor and the event will be logged in HK (ER–flag, see DV1, Table 19).

8.4 DPU control of sensor

Command sequences for initialization of the sensor, normal operation, and shutdown are summarized in Table 11 to Table 13. During Initialization the DPU sends a command, may check the status of the sensor, sends a command, and so on. The status is checked by requesting a single engineering mode packet after completion of each step. Engineering mode packet requests are for simplicity, not shown in Table 11 and Table 13.

The minimum time between two sensor commands is 31.25ms. Note that sensor mode changes will be executed at the next 0.25Hz clock pulse.

8.4.1 Initialization sequence

Step	Initialization
1	Switch on sensor +3.3V at t=0
2	Switch on sensor +5.0V at t=0
3	Switch on sensor +/-12V at t=0
4	Wait at least 130ms to allow for RAM initialization (**note 1**)
5	Start send Sync pulse
6	Wait 4 seconds, subcommutated HK data becomes valid after this step.
7	Set sensor mode
8	Wait until next Sync pulse
9	Select SV **"zero"** table for SV control, table index 0 (**note 2**)
10	Write control tables of all the sweeping high voltages for all tables except index 0 (**note 3**)
11	Set all HVPS references to zero HV level set enable HV level set (at level 0)
12	Set HV_safety_DISABLE for measurement in space or under enough vacuum Do not set for testing under atmospheric pressure (**note 4**) HV on enable HV safety disable
13	Switch on HVPS power (**note 5**) HV on enable HV on
14	Set HV_Ref (controlled by Ref1 in Figure 8) and increase gradually gradually (see chapter 8.4.5 for ramping speed): HV level set enable HV level set (at level 1) HV level set enable HV level set (at level 2) ....
15	Select SVx_table for SV control of the measurement
16	Set HV_Def and increase gradually (see chapter 8.4.5 for ramping speed).
17	Set HV_TOF and HV_StopMCP and increased both gradually and simultaneously gradually (see chapter 8.4.5 for ramping speed) **(note 6)**
18	Set HV_StartMCP and increase gradually (see chapter 8.4.5 for ramping speed).
19	Perform health check after initialisation and once per commanded period. Default every 4096 sec.

Table 11

Note 1: Just after power on the sensor will start sending data packets every 125ms. These packets can be ignored until the clock pulse is established in the next step. Afterwards the data stream can be used to extract sub commutated HK data.

Note 2: With the SV zero table (table index 0), SV outputs are kept as close to zero as possible.

Note 3: The currently selected table can not be overwritten. The 'zero' table is thus excluded in this step. However, the 'zero' table is initialized with '0' anyway, so no problem occours.

Note 4: This is VERY important. Mistake could cause complete sensor loss

Note 5: Do NOT turn on the HVPS under bad vacuum conditions. "Safety enable" is not enough. Note that the "safety enable" works under atmospheric pressure.

Note 6: **There is a strict restriction of HV control when ramping up/down HV_STOPMCP and HV_TOF: Voltage difference between them must be less than 800V anytime**, since the gap between the corresponding electrodes is only 0.8 mm wide.

8.4.2 Sampling sequence

Sampling (normal measurement cycle)
The DPU shall perform the following every 125 ms: Receive data from the CENA. No further commanding after setting sensor mode is necessary to obtain data. The sensor performs sweeping of voltages autonomously based on active SV table. **However, there must be a possibility to send commands to the sensor while in sampling mode for commissioning purposes. Such commands will be provided by TC from ground and typically consist of but not be limited to HV-related commands. Sampling should not stop when sending such commands.**

Table 12

8.4.3 Nominal shutdown sequence

Step	Shutdown
1	Select SVx_Table **"zero"** for SV control **(note 1)**
2	Decrease HV_StartMCP gradually (see chapter 8.4.5 for ramping speed).
3	Decrease HV_StopMCP and HV_TOF gradually (see chapter 8.4.5 for ramping speed) **(note 2)**
4	Decrease HV_TOF gradually (see chapter 8.4.5 for ramping speed)
5	Decrease HV_Def gradually (see chapter 8.4.5 for ramping speed)
6	Decrease HV_Ref gradually (see chapter 8.4.5 for ramping speed)
7	Wait 4 seconds
8	Send command to switch off HVPS power HV off
9	Inhibit Sync pulse
10	Switch off sensor power +/-12 V at t=T
11	Switch off sensor power +5 V at t=T
12	Switch off sensor power +3.3 V at t=T

Table 13

Note 1 By using table index 0 for SV tables, SV provides the smallest possible voltages.

Note 2: **There is a strict restriction of HV control when ramping up/down HV_STOPMCP and HV_TOF: Voltage difference between them must be less than 800V anytime**, since the gap between the corresponding electrodes is 0.8 mm wide only.

8.4.4 Emergency shutdown sequences

8.4.4.1 Following DPU Watchdog Reset

Step	Watchdog reset of DPU
1	Reboot DPU
2	Switch off sensor power +/-12 V
3	Switch off sensor power +5 V
4 5 6	Switch off sensor power +3.3 V Send packet to S/C indicating reboot Wait for TC to initiate sensor initialization sequence.

Table 14

No HV ramping takes place.

8.4.4.2 Following S/C reset of DPU

Step	Reset of DPU by S/C
1	Reboot DPU
2	Switch off sensor power +/-12 V
3	Switch off sensor power +5 V
4 5 6	Switch off sensor power +3.3 V Send packet to S/C indicating reboot Wait for TC to initiate sensor initialization sequence.

Table 15

No HV ramping takes place.

8.4.5 HV ramping constraints

Some high voltages must be changed (ramped up or down) only gradually. Voltages not mentioned in Table 16 do not have such restrictions. As exception, HV ramping does not take place during emergency shutdown sequences.

High voltage	Max step size [Volts/step] (note 1)	Default step size [Volts/step] (note 1)	max. change rate [Volts/sec]	Default change rate [Volts/sec]
HV_REF	200 (Note 2)	200	500	200
HV_DEF	200	200	500	200
HV_STARTMCP	100	50	100	50
HV_STOPMCP	100	50	100	50
HV_TOF	100	50	100	50

Table 16

Note 1) This value may be increased if test show it is feasible.
Note 2) It is recommended to program one step per second but more frequent programming with smaller step size is also acceptable.

'Default' in the above table means that the value can be changed e.g. by RAM-patch TC or similar. Default values for the voltages at the end of the ramping sequence will be determined during FM calibration and during commissioning when the instrument is in its real environment.

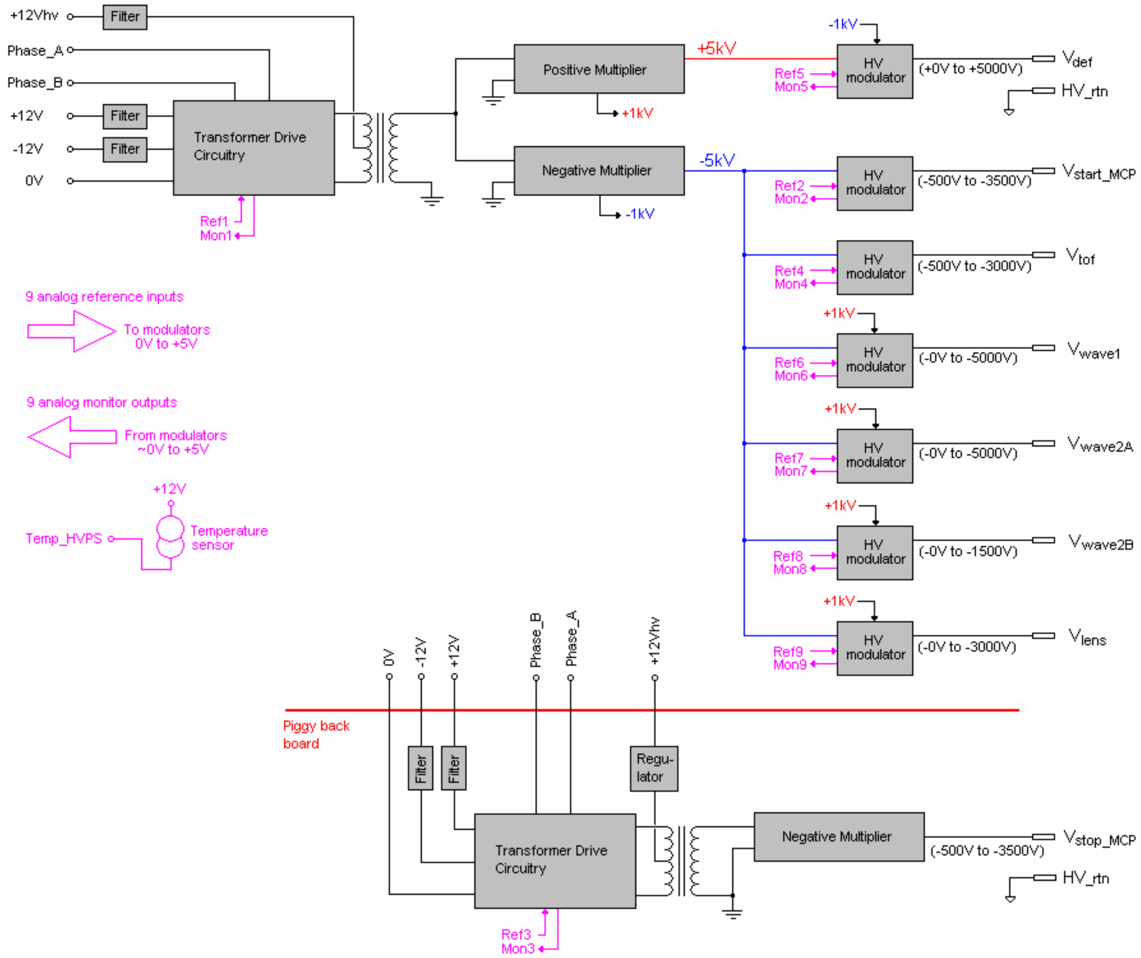


Figure 8 CENA HVPS block diagram

8.5 List of commands

Commands from DPU to CENA consist of a command type (CT) with a number of command parameters (CP), depending on type of command.

	B7	B6	B5	B4	B3	B2	B1	B0	HEX	Command	Description
CT	0	0	0	0	0	0	0	1	0x01h	HV_on_enable	Set HV_on_enable flag. This command unlocks the functionality of the HV_on and HV_safety_disable commands.
CP	1	0	0	0	0	0	0	0	0x80h		
CT	0	0	0	0	0	0	1	0	0x02h	HV_on_disable	Clear HV_on_enable flag
CP	0	0	0	0	0	0	0	0	0x00h		
CT	0	0	0	0	0	0	1	1	0x03h	HV_on	Turn on main HV oscillator. No action is made (command is ignored) when HV_on_enable flag is not set. After execution, HV_on_enable flag is cleared.
CP	0	0	0	0	0	0	0	0	0x00h		
CT	0	0	0	0	0	1	0	0	0x04h	HV_off	Switch Main HV off
CP	0	0	0	0	0	0	0	0	0x00h		
CT	0	0	0	0	0	1	1	1	0x05h	HV_safety_enable	Set HV safety enable flag. When HV safety is enabled, HV output level is limited to lower level such as for test on ground. The flag is automatically set after power-on reset.
CP	0	0	0	0	0	0	0	0	0x00h		
CT	0	0	0	0	0	1	1	0	0x06h	HV_safety_disable	Clear HV safety enable flag (removes limitations on possible HV values). No HV commands resulting in higher voltage output are executed when HV safety enable is set. No action is made by this command when HV_on_enable flag is not set. After execution, HV_on_enable flag is cleared.
CP	1	0	0	0	0	0	0	0	0x80h		
CT	0	0	0	0	0	1	1	1	0x07h	HV_level_set_enable	Set HV_level_set_enable flag. This command unlocks the functionality of the HV_level_set command below. This command must precede a HV_level_set command for the later to be effective.
CP	0	0	0	0	0	0	0	0	0x00h		
CT	0	0	0	0	1	0	0	0	0x08h	HV_level_set_disable	Clear HV_level_set_enable flag
CP	0	0	0	0	0	0	0	0	0x00h		
CT	0	0	0	0	1	0	0	1	0x09h	HV_level_set	Change HV reference voltage (Ref1-Ref9 in Figure 8). The command is ignored if HV_level_set_enable flag is not set. After execution, HV_level_set_enable flag is cleared.
CP1						0	0	0		HV_Main	Select HV_Main (Ref1)

<table>
<tr><th></th><th>B7</th><th>B6</th><th>B5</th><th>B4</th><th>B3</th><th>B2</th><th>B1</th><th>B0</th><th>HEX</th><th>Command</th><th>Description</th></tr>
<tr><td>“</td><td></td><td></td><td></td><td></td><td></td><td>0</td><td>0</td><td>1</td><td></td><td>HV_StartMCP</td><td>Select HV_StopMCP (Ref2)</td></tr>
<tr><td>“</td><td></td><td></td><td></td><td></td><td></td><td>0</td><td>1</td><td>0</td><td></td><td>HV_StopMCP</td><td>Select HV_StopMCP (Ref3)</td></tr>
<tr><td>“</td><td></td><td></td><td></td><td></td><td></td><td>0</td><td>1</td><td>1</td><td></td><td>HV_TOF</td><td>Select HV_TOF (Ref4)</td></tr>
<tr><td>“</td><td></td><td></td><td></td><td></td><td></td><td>1</td><td>0</td><td>0</td><td></td><td>HV_Def</td><td>Select HV_Def (Ref5)</td></tr>
<tr><td>CP2</td><td></td><td></td><td></td><td></td><td>n</td><td>n</td><td>n</td><td>n</td><td></td><td>HV level [11:8]</td><td>Value for reference input (see Figure 8). except for HV_Def, the references are 8 Bit values, bits [11:8] must be 0 in this case. HV_Def uses 12 bit values.</td></tr>
<tr><td>CP3</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td></td><td>HV level [7:0]</td><td></td></tr>
<tr><td>CT</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td><td>0</td><td>1</td><td>0</td><td>0x0Ah</td><td>Change_selected_SV_table</td><td>Change active SV table.
SV table index is in the range of 0x0 ... 0xF (15 dec).
Index 0x0 refers to the “zero” SV table (which is selected during initialization)
For practical reasons the same index is selected for all 4 SV_Table values below.</td></tr>
<tr><td>CP1</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td></td><td>SV2_Table [7:4], SV1_Table [3:0]</td><td>SV1_Table: SV table index used to sweep HV_Wave1
SV2_Table: SV table index used to sweep HV_Wave2A</td></tr>
<tr><td>CP2</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td></td><td>SV4_Table [7:4], SV3_Table [3:0]</td><td>SV3_Table: SV table index used to sweep HV_Wave2B
SV4_Table: SV table index used to sweep HV_Lens</td></tr>
<tr><td>CT</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td><td>0</td><td>1</td><td>1</td><td>0x0Bh</td><td>Observation_mode</td><td>Set to Observation mode</td></tr>
<tr><td>CP1</td><td>S1</td><td>S0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>M1</td><td>M0</td><td></td><td>Select observation mode</td><td><table>
<tr><td>S1</td><td>S0</td><td></td></tr>
<tr><td>--</td><td>0</td><td>S1 bit ignored</td></tr>
<tr><td>0</td><td>1</td><td>asynchronous mode set</td></tr>
<tr><td>1</td><td>1</td><td>synchronous mode set</td></tr>
<tr><td>M1</td><td>M0</td><td></td></tr>
<tr><td>0</td><td>0</td><td>coincidence</td></tr>
<tr><td>0</td><td>1</td><td>counter</td></tr>
<tr><td>1</td><td>0</td><td>engineering</td></tr>
<tr><td>1</td><td>1</td><td>not defined</td></tr>
</table></td></tr>
<tr><td>CP2</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td></td><td>Param1</td><td>Reserved (use 0x00 as value)</td></tr>
<tr><td>CP3</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td></td><td>Param2</td><td>Reserved (use 0x00 as value)</td></tr>
<tr><td>CP4</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td></td><td>Param3</td><td>Event data reporting selection bitmask [15:8] for counter end coincidence mode
Parambit=0 don’t record this type of event
Parambit=1 record this type of event<table>
<tr><td>Param [bit]</td><td>START RING</td><td>START SECTOR</td><td>STOP SECTOR</td><td>STOP MESH</td></tr>
</table></td></tr>
</table>

<table>
<tr><th></th><th>B7</th><th>B6</th><th>B5</th><th>B4</th><th>B3</th><th>B2</th><th>B1</th><th>B0</th><th>HEX</th><th>Command</th><th>Description</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>
<table>
<tr><td>3 [7]</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>3 [6]</td><td>1</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>3 [5]</td><td>0</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>3 [4]</td><td>0</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>3 [3]</td><td>1</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>3 [2]</td><td>X</td><td>1</td><td>X</td><td>X</td></tr>
<tr><td>3 [1]</td><td>X</td><td>X</td><td>1</td><td>X</td></tr>
<tr><td>3 [0]</td><td>X</td><td>X</td><td>X</td><td>1</td></tr>
</table>
1 - signal present, 0 - no signal present, X - don’t care</td></tr>
<tr><td>CP5</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td></td><td>Param4</td><td>Event data reporting selection bitmask [7:0] for counter end coincidence mode
Parambit=0 don’t record this type of event
Parambit=1 record this type of event
Res. = reserved (do not use)
Use 0x00 as default value for Param4
<table>
<tr><th>Param [bit]</th><th>START RING</th><th>START SECTOR</th><th>STOP SECTOR</th><th>STOP MESH</th></tr>
<tr><td>4 [7]</td><td>Res.</td><td>Res</td><td>Res</td><td>Res</td></tr>
<tr><td>4 [6]</td><td>Res.</td><td>Res</td><td>Res</td><td>Res</td></tr>
<tr><td>4 [5]</td><td>Res.</td><td>Res</td><td>Res</td><td>Res</td></tr>
<tr><td>4 [4]</td><td>Res.</td><td>Res</td><td>Res</td><td>Res</td></tr>
<tr><td>4 [3]</td><td>Res.</td><td>Res</td><td>Res</td><td>Res</td></tr>
<tr><td>4 [2]</td><td>Res.</td><td>Res</td><td>Res</td><td>Res</td></tr>
<tr><td>4 [1]</td><td>Res.</td><td>Res</td><td>Res</td><td>Res</td></tr>
<tr><td>4 [0]</td><td>Res.</td><td>Res</td><td>Res</td><td>Res</td></tr>
</table>
1 - signal present, 0 - no signal present, X - don’t care</td></tr>
<tr><td>CP6</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td></td><td>Dead_time [7:0]</td><td>Actual dead time = Dead time[7:0] * 15.6 / 256 [ms]</td></tr>
<tr><td>CT</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td><td>1</td><td>0</td><td>0</td><td>0x0Ch</td><td>Discrimination_level set</td><td>Set Preamplifier sensitivity (threshold)</td></tr>
<tr><td>CP1</td><td></td><td></td><td></td><td></td><td></td><td>n</td><td>n</td><td>n</td><td></td><td>Select discrimination [2:0]</td><td>Set discrimination level for MCP output signal (Preamplifier threshold)</td></tr>
<tr><td>CP2</td><td></td><td></td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td></td><td>Start_Ring1_Ch1</td><td>Set discrimination level for Chxx (xx=1 to 20)</td></tr>
<tr><td>“</td><td></td><td></td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td><td></td><td>Start_Ring2_Ch2</td><td></td></tr>
<tr><td>“</td><td></td><td></td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td><td>0</td><td></td><td>Start_Ring3_Ch3</td><td></td></tr>
<tr><td>“</td><td></td><td></td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td><td>1</td><td></td><td>Start_Ring4_Ch4</td><td></td></tr>
<tr><td>“</td><td></td><td></td><td>0</td><td>1</td><td>0</td><td>0</td><td>0</td><td>0</td><td></td><td>Start_Sector1_Ch5</td><td></td></tr>
<tr><td>“</td><td></td><td></td><td>0</td><td>1</td><td>0</td><td>0</td><td>0</td><td>1</td><td></td><td>Start_Sector2_Ch6</td><td></td></tr>
</table>

	B7	B6	B5	B4	B3	B2	B1	B0	HEX	Command	Description
“			0	1	0	0	1	0		Start_Sector3_Ch7	
“			0	1	0	0	1	1		Start_Sector4_Ch8	
“			0	1	0	1	0	0		Start_Sector5_Ch9	
“			0	1	0	1	0	1		Start_Sector6_Ch10	
“			0	1	0	1	1	0		Start_Sector7_Ch11	
“			1	0	0	0	0	0		Stop_Sector1_Ch12	
“			1	0	0	0	0	1		Stop_Sector2_Ch13	
“			1	0	0	0	1	0		Stop_Sector3_Ch14	
“			1	0	0	0	1	1		Stop_Sector4_Ch15	
“			1	0	0	1	0	0		Stop_Sector5_Ch16	
“			1	0	0	1	0	1		Stop_Sector6_Ch17	
“			1	0	0	1	1	0		Stop_Sector7_Ch18	
“			1	0	0	1	1	1		Stop_Sector8_Ch19	
“			1	0	1	0	0	0		Stop_Mesh1_Ch20	
CT	0	0	0	0	1	1	0	1	0x0Dh	Cal_mode	Set to Calibration mode
CP1	sx	s2	s1	s0	0	rx	r1	r0		Cal mode1	Sx: Start sector on/off, on = 1 s2:s0 Start Sector number to which cal pulse is introduced rx Start Ring on/off, on = 1 r1:r0 Start Ring number to which cal pulse is introduced
CP2	f2	f1	f0	mx	sx	s2	s1	s0		Cal mode2	f2:f0 Frequency of cal pulse 0 - off, 1 - 2.5kHz, 2 - 5kHz, 3 - 10kHz, 4 - 50kHz 5 - 100kHz, 6 - 500kHz, 7 - 1000kHz Mx Stop Mesh on/off, on = 1 Sx Stop Sector on/off, on = 1 s2:s0 Stop Sector number to which cal pulse is introduced
CP3	n	n	n	n	n	n	n	n		Cal timing1	Set timing of Start Ring pulse. 0xff corresponds to 32us relative to arbitrary reference time.
CP4	n	n	n	n	n	n	n	n		Cal timing2	Set timing of Start Sector pulse. 0xff corresponds to 32us relative to same reference time as above
CP5	n	n	n	n	n	n	n	n		Cal timing3	Set timing of Stop Sector pulse. 0xff corresponds to 32us relative to same reference time as above
CP6	n	N	n	n	n	n	n	n		Cal timing4	Set timing of Stop Mesh pulse. 0xff corresponds to 32us relative to same reference time as above
CT	0	0	0	0	1	1	1	0	0x0Eh	Start_anode_enable	Enable signal from MCP Start anodes
CP1	n	0	0	0	0	0	0	0		Start_Ring1_Ch1	n = 0 disable, n = 1 enable. Anode selector [5:0].
“	n	0	0	0	0	0	0	1		Start_Ring2_Ch2	

	B7	B6	B5	B4	B3	B2	B1	B0	HEX	Command	Description
“	n	0	0	0	0	0	1	0		Start_Ring3_Ch3	
“	n	0	0	0	0	0	1	1		Start_Ring4_Ch4	
“	n	0	0	1	0	0	0	0		Start_Sector1_Ch5	
“	n	0	0	1	0	0	0	1		Start_Sector2_Ch6	
“	n	0	0	1	0	0	1	0		Start_Sector3_Ch7	
“	n	0	0	1	0	0	1	1		Start_Sector4_Ch8	
“	n	0	0	1	0	1	0	0		Start_Sector5_Ch9	
“	n	0	0	1	0	1	0	1		Start_Sector6_Ch10	
“	n	0	0	1	0	1	1	0		Start_Sector7_Ch11	
“	n	0	1	0	0	0	0	0		Stop_Sector1_Ch12	
“	n	0	1	0	0	0	0	1		Stop_Sector2_Ch13	
“	n	0	1	0	0	0	1	0		Stop_Sector3_Ch14	
“	n	0	1	0	0	0	1	1		Stop_Sector4_Ch15	
“	n	0	1	0	0	1	0	0		Stop_Sector5_Ch16	
“	n	0	1	0	0	1	0	1		Stop_Sector6_Ch17	
“	n	0	1	0	0	1	1	0		Stop_Sector7_Ch18	
“	n	0	1	0	0	1	1	1		Stop_Sector8_Ch19	
“	n	0	1	0	1	0	0	0		Stop_Mesh1_Ch20	
CT	0	0	0	0	1	1	1	1	0x0Fh	NOP	
CT	0	0	0	1	0	0	0	0	0x10h	Write_SV_table	Write SV sweep table to IFE RAM. Will change mode. Note that the currently selected table cannot be modified.
CP1	0	0	n	n	n	n	n	n		SV type [5:4] Table ID 3:0]	SV type: 0x0 - SV_Wave1, 0x1 - SV_Wave2A, 0x2 - SV_wave2B, 0x3 - SV_Lens
CP2	0	0	0	0	n	n	n	n		Tbldata1 [11:8]	DAC input at each energy step
CP3	n	n	n	n	n	n	n	n		Tbldata1 [7:0]	
CP4	0	0	0	0	n	n	n	n		Tbldata2 [11:8]	
CP5	n	n	n	n	n	n	n	n		Tbldata2 [7:0]	
CP6	0	0	0	0	n	n	n	n		Tbldata3 [11:8]	
CP7	n	n	n	n	n	n	n	n		Tbldata3 [7:0]	
CP8	0	0	0	0	n	n	n	n		Tbldata4 [11:8]	
CP9	n	n	n	n	n	n	n	n		Tbldata4 [7:0]	
CP10	0	0	0	0	n	n	n	n		Tbldata5 [11:8]	
CP11	n	n	n	n	n	n	n	n		Tbldata5 [7:0]	
CP12	0	0	0	0	n	n	n	n		Tbldata6 [11:8]	
CP13	n	n	n	n	n	n	n	n		Tbldata6 [7:0]	

	B7	B6	B5	B4	B3	B2	B1	B0	HEX	Command	Description
CP14	0	0	0	0	n	n	n	n		Tbldata7 [11:8]	
CP15	n	n	n	n	n	n	n	n		Tbldata7 [7:0]	
CP16	0	0	0	0	n	n	n	n		Tbldata8 [11:8]	
CP17	n	n	n	n	n	n	n	n		Tbldata8 [7:0]	
CT	0	0	0	1	0	0	0	1	0x11h	Read_SV_table	Read SV sweep table from IFE RAM. Read data is sent via telemetry i/f.
CP1	0	0	n	n	n	n	n	n		SV type [5:4] Table ID [3:0]	SV type: 0x0 - SV_Wave1, 0x1 - SV_Wave2A, 0x2 - SV_wave2B, 0x3 - SV_Lens
CT									0x12h	Read_engineering data	Data is sent via telemetry i/f
CT									0x13h	Clear_command_error_flag	Clear ER bit in DV1 of HK data

Table 17 List of commands

8.6 Format of data sent to DPU following a sensor command

Some of the commands listed in section 8.5 (Read_SV_table, Read_engineering_data) result in data which is transmitted to the DPU. These data are sent in between possible science or enginering packets as described in section 7 and will the same frame format except that the HK subchannel byte is replaced by padding. The packet format of these data is as follows:

a) SV sweep tables. After reception of the command Read_SV_table, the content of table RAM specified is sent. The sensor may send more bytes than needed to represent the table, up to 400 bytes total. The packet length field always indicates the number of bytes sent. Values of unused DV elements are undefined.

	B7	B6	B5	B4	B3	B2	B1	B0	HEX value	Description	Note
DT1	1	0	0	0	0	0	1	1	83h	Packet ID [7:0]	
DT2	0									Slot [6:0]	
DT3	0	0	0	0	0	0	0	0	00h		Filling byte inserted to have all packets starting the content at 4th byte.
DV1	0	0	n	n	n	n	n	n		SV type [5:4] TableID [3:0]	SV type: 0x0 - SV_Wave1, 0x1 - SV_Wave2A, 0x2 - SV_wave2B, 0x3 - SV_Lens
DV2	0	0	0	0	n	n	n	n		Tbldata1 [11:8]	
DV3	n	n	n	n	n	n	n	n		Tbldata1 [7:0]	
DV4	0	0	0	0	n	n	n	n		Tbldata2 [11:8]	
DV5	n	n	n	n	n	n	n	n		Tbldata2 [7:0]	
DV6	0	0	0	0	n	n	n	n		Tbldata3 [11:8]	
DV7	n	n	n	n	n	n	n	n		Tbldata3 [7:0]	
DV8	0	0	0	0	n	n	n	n		Tbldata4 [11:8]	
DV9	n	n	n	n	n	n	n	n		Tbldata4 [7:0]	
DV10	0	0	0	0	n	n	n	n		Tbldata5 [11:8]	
DV11	n	n	n	n	n	n	n	n		Tbldata5 [7:0]	
DV12	0	0	0	0	n	n	n	n		Tbldata6 [11:8]	
DV13	n	n	n	n	n	n	n	n		Tbldata6 [7:0]	
DV14	0	0	0	0	n	n	n	n		Tbldata7 [11:8]	
DV15	n	n	n	n	n	n	n	n		Tbldata7 [7:0]	
DV16	0	0	0	0	n	n	n	n		Tbldata8 [11:8]	
DV17	n	n	n	n	n	n	n	n		Tbldata8 [7:0]	Padding up to DV397 may follow.

Table 18 SV table packet layout

b) Engineering packets.

	B7	B6	B5	B4	B3	B2	B1	B0	Hex	Description	Note
DT1	1	0	0	0	0	0	1	0	82h	Packet ID	
DT2	0	n	n	n	n	n	n	n		Slot [6:0]	
DT3	0	0	0	0	0	0	0	0	00h		Filling byte inserted to have all packets starting the content at 4th byte (identical to packet type 02hex)
DV1	ER	0	SE	PE	0	0	S	P		Flags	P HV_Main power 0=off, 1=on S HV_safety_enable 0=set (enable), 1=unset (disable) PE HV_on_enable 0=unset, 1=set SE HV_level_set_enable 0=unset, 1=set ER Error flag 0=all checksums ok since last clearing 1=command received with illegal checksum
DV2	0	0	0	0	n	n	n	n	n	H1Level [11:8]	HV_Main monitor (upper)
DV3	n	n	n	n	n	n	n	n	n	H1Level [7:0]	HV_Main monitor (lower)
DV4	0	0	0	0	n	n	n	n	n	H2Level [11:8]	HV_StartMCP monitor (upper
DV5	n	n	n	n	n	n	n	n	n	H2Level [7:0]	HV_StartMCP monitor (lower)
DV6	0	0	0	0	n	n	n	n	n	H3Level [11:8]	HV_StopMCP monitor (upper
DV7	n	n	n	n	n	n	n	n	n	H3Level [7:0]	HV_StopMCP monitor (lower)
DV8	0	0	0	0	n	n	n	n	n	H4Level [11:8]	HV_TOF monitor (upper)
DV9	n	n	n	n	n	n	n	n	n	H4Level [7:0]	HV_TOF monitor (lower)
DV10	0	0	0	0	n	n	n	n	n	H5Level [11:8]	HV_Def monitor (upper)
DV11	n	n	n	n	n	n	n	n	n	H5Level [7:0]	HV_Def monitor (lower)
DV12	0	0	0	0	n	n	n	n	n	TempIFE [11:8]	IFE temperature (upper)
DV13	n	n	n	n	n	n	n	n	n	TempIFE [7:0]	IFE temperature (lower)
DV14	0	0	0	0	n	n	n	n	n	TempHVPS [11:8]	HVPS temperature (upper)
DV15	n	n	n	n	n	n	n	n	n	TempHVPS [7:0]	HVPS temperature (lower)
DV16	n	n	n	n	n	n	n	n	n	SV2_TABLE [7:4] SV1_TABLE [3:0]	SV1_TABLE: SV_WAVE1 SV2_TABLE: SV_WAVE2A
DV17	n	n	n	n	n	n	n	n	n	SV4_TABLE [7:4] SV3_TABLE [3:0]	SV3_TABLE: SV_WABE2B SV4_TABLE: SV_LENS
DV18	S1	0	0	0	0	0	M1	M0		Observation mode	S1=0 synchronous mode S1=1 asynchronous mode M1 M0 0 0 coincidence

	B7	B6	B5	B4	B3	B2	B1	B0	Hex	Description	Note
											0 1 counter 1 0 engineering 1 1 not defined
DV19	n	n	n	n	n	n	n	n		Param1	Reserved
DV20	n	n	n	n	n	n	n	n		Param2	Reserved
DV21	n	n	n	n	n	n	n	n		Param3	Coincidence and Counter mode: Event selection bitmask [15:8], reserved otherwise
DV22	n	n	n	n	n	n	n	n		Param4	Coincidence and Counter mode: Event selection bitmask [7:0], reserved otherwise
DV23	n	n	n	n	n	n	n	n		Dead time [7:0]	actual dead time = Dead time[7:0] * 15.6 / 256 [ms]
DV24	n	n	n	n	n	n	n	n		Ch2[7:4], Ch1[3:0]	Definition of Ch – see Figure 4 CHxx: preamp ID (xx=1..20) CHxx[a+3:a]: E D3 D2 D1 E=0: MCP signal input disable E=1: MCP signal input enable D: discrimination level
DV25	n	n	n	n	n	n	n	n		Ch4 [7:4], Ch3 [3:0]	
DV26	n	n	n	n	n	n	n	n		Ch8 [7:4], Ch7 [3:0]	
DV27	n	n	n	n	n	n	n	n		Ch10 [7:4], Ch9 [3:0]	
DV28	n	n	n	n	n	n	n	n		Ch10 [7:4], Ch9 [3:0]	
DV29	n	n	n	n	n	n	n	n		Ch12 [7:4], Ch11 [3:0]	
DV30	n	n	n	n	n	n	n	n		Ch14 [7:4], Ch13 [3:0]	
DV31	n	n	n	n	n	n	n	n		Ch16 [7:4], Ch15 [3:0]	
DV32	n	n	n	n	n	n	n	n		Ch18 [7:4], Ch17 [3:0]	
DV33	n	n	n	n	n	n	n	n		Ch20 [7:4], Ch19 [3:0]	
DV34	n	n	n	n	n	n	n	n		Psync counter [15:8]	Number of Sync pulses received from DPU since IFE power on
DV35	n	n	n	n	n	n	n	n		Psync counter [7:0]	
DV36	n	n	n	n	n	n	n	n		Base counter [15:8]	Number of “Sync pulse” intervals elapsed since IFE power on
DV37	n	n	n	n	n	n	n	n		Base counter [7:0]	
DV38	0	0	0	0	n	n	n	n		S1Level 1 [11:8]	SV_WAVE1 monitor level 1 (upper)
DV39	n	n	n	n	n	n	n	n		S1Level 1 [7:0]	SV_WAVE1 monitor level 1 (lower)
DV40	0	0	0	0	n	n	n	n		S1Level 2 [11:8]	SV_WAVE1 monitor level 2 (upper)
DV41	n	n	n	n	n	n	n	n		S1Level 2 [7:0]	SV_WAVE1 monitor level 2 (lower)

	B7	B6	B5	B4	B3	B2	B1	B0	Hex	Description	Note
DV42	0	0	0	0	n	n	n	n		S1Level 3 [11:8]	SV_WAVE1 monitor level 3 (upper)
DV43	n	n	n	n	n	n	n	n		S1Level 3 [7:0]	SV_WAVE1 monitor level 3 (lower)
DV44	0	0	0	0	n	n	n	n		S1Level 4 [11:8]	SV_WAVE1 monitor level 4 (upper)
DV45	n	n	n	n	n	n	n	n		S1Level 4 [7:0]	SV_WAVE1 monitor level 4 (lower)
DV46	0	0	0	0	n	n	n	n		S1Level 5 [11:8]	SV_WAVE1 monitor level 5 (upper)
DV47	n	n	n	n	n	n	n	n		S1Level 5 [7:0]	SV_WAVE1 monitor level 5 (lower)
DV48	0	0	0	0	n	n	n	n		S1Level 6 [11:8]	SV_WAVE1 monitor level 6 (upper)
DV49	n	n	n	n	n	n	n	n		S1Level 6 [7:0]	SV_WAVE1 monitor level 6 (lower)
DV50	0	0	0	0	n	n	n	n		S1Level 7 [11:8]	SV_WAVE1 monitor level 7 (upper)
DV51	n	n	n	n	n	n	n	n		S1Level 7 [7:0]	SV_WAVE1 monitor level 7 (lower)
DV52	0	0	0	0	n	n	n	n		S1Level 8 [11:8]	SV_WAVE1 monitor level 8 (upper)
DV53	n	n	n	n	n	n	n	n		S1Level 8 [7:0]	SV_WAVE1 monitor level 8 (lower)
DV54	0	0	0	0	n	n	n	n		S2Level 1 [11:8]	SV_WAVE2A monitor level 1(upper)
DV55	n	n	n	n	n	n	n	n		S2Level 1 [7:0]	SV_WAVE2A monitor level 1 (lower)
DV56	0	0	0	0	n	n	n	n		S2Level 2 [11:8]	SV_WAVE2A monitor level 2 (upper)
DV57	n	n	n	n	n	n	n	n		S2Level 2 [7:0]	SV_WAVE2A monitor level 2 (lower)
DV58	0	0	0	0	n	n	n	n		S2Level 3 [11:8]	SV_WAVE2A monitor level 3 (upper)
DV59	n	n	n	n	n	n	n	n		S2Level 3 [7:0]	SV_WAVE2A monitor level 3 (lower)
DV60	0	0	0	0	n	n	n	n		S2Level 4 [11:8]	SV_WAVE2A monitor level 4 (upper)
DV61	n	n	n	n	n	n	n	n		S2Level 4 [7:0]	SV_WAVE2A monitor level 4 (lower)
DV62	0	0	0	0	n	n	n	n		S2Level 5 [11:8]	SV_WAVE2A monitor level 5 (upper)
DV63	n	n	n	n	n	n	n	n		S2Level 5 [7:0]	SV_WAVE2A monitor level 5 (lower)
DV64	0	0	0	0	n	n	n	n		S2Level 6 [11:8]	SV_WAVE2A monitor level 6 (upper)
DV65	n	n	n	n	n	n	n	n		S2Level 6 [7:0]	SV_WAVE2A monitor level 6 (lower)
DV66	0	0	0	0	n	n	n	n		S2Level 7 [11:8]	SV_WAVE2A monitor level 7 (upper)
DV67	n	n	n	n	n	n	n	n		S2Level 7 [7:0]	SV_WAVE2A monitor level 7 (lower)
DV68	0	0	0	0	n	n	n	n		S2Level 8 [11:8]	SV_WAVE2A monitor level 8 (upper)
DV69	n	n	n	n	n	n	n	n		S2Level 8 [7:0]	SV_WAVE2A monitor level 8 (lower)
DV70	0	0	0	0	n	n	n	n		S3Level 1 [11:8]	SV_WAVE2B monitor level 1 (upper)
DV71	n	n	n	n	n	n	n	n		S3Level 1 [7:0]	SV_WAVE2B monitor level 1 (lower)
DV72	0	0	0	0	n	n	n	n		S3Level 2 [11:8]	SV_WAVE2B monitor level 2 (upper)
DV73	n	n	n	n	n	n	n	n		S3Level 2 [7:0]	SV_WAVE2B monitor level 2 (lower)
DV74	0	0	0	0	n	n	n	n		S3Level 3 [11:8]	SV_WAVE2B monitor level 3 (upper)
DV75	n	n	n	n	n	n	n	n		S3Level 3 [7:0]	SV_WAVE2B monitor level 3 (lower)
DV76	0	0	0	0	n	n	n	n		S3Level 4 [11:8]	SV_WAVE2B monitor level 4 (upper)

	B7	B6	B5	B4	B3	B2	B1	B0	Hex	Description	Note
DV77	n	n	n	n	n	n	n	n		S3Level 4 [7:0]	SV_WAVE2B monitor level 4 (lower)
DV78	0	0	0	0	n	n	n	n		S3Level 5 [11:8]	SV_WAVE2B monitor level 5 (upper)
DV79	n	n	n	n	n	n	n	n		S3Level 5 [7:0]	SV_WAVE2B monitor level 5 (lower)
DV80	0	0	0	0	n	n	n	n		S3Level 6 [11:8]	SV_WAVE2B monitor level 6 (upper)
DV81	n	n	n	n	n	n	n	n		S3Level 6 [7:0]	SV_WAVE2B monitor level 6 (lower)
DV82	0	0	0	0	n	n	n	n		S3Level 7 [11:8]	SV_WAVE2B monitor level 7 (upper)
DV83	n	n	n	n	n	n	n	n		S3Level 7 [7:0]	SV_WAVE2B monitor level 7 (lower)
DV84	0	0	0	0	n	n	n	n		S3Level 8 [11:8]	SV_WAVE2B monitor level 8 (upper)
DV85	n	n	n	n	n	n	n	n		S3Level 8 [7:0]	SV_WAVE2B monitor level 8 (lower)
DV86	0	0	0	0	n	n	n	n		S4Level 1 [11:8]	SV_LENS monitor level 1 (upper)
DV87	n	n	n	n	n	n	n	n		S4Level 1 [7:0]	SV_LENS monitor level 1 (lower)
DV88	0	0	0	0	n	n	n	n		S4Level 2 [11:8]	SV_LENS monitor level 2 (upper)
DV89	n	n	n	n	n	n	n	n		S4Level 2 [7:0]	SV_LENS monitor level 2 (lower)
DV90	0	0	0	0	n	n	n	n		S4Level 3 [11:8]	SV_LENS monitor level 3 (upper)
DV91	n	n	n	n	n	n	n	n		S4Level 3 [7:0]	SV_LENS monitor level 3 (lower)
DV92	0	0	0	0	n	n	n	n		S4Level 4 [11:8]	SV_LENS monitor level 4 (upper)
DV93	n	n	n	n	n	n	n	n		S4Level 4 [7:0]	SV_LENS monitor level 4 (lower)
DV94	0	0	0	0	n	n	n	n		S4Level 5 [11:8]	SV_LENS monitor level 5 (upper)
DV95	n	n	n	n	n	n	n	n		S4Level 5 [7:0]	SV_LENS monitor level 5 (lower)
DV96	0	0	0	0	n	n	n	n		S4Level 6 [11:8]	SV_LENS monitor level 6 (upper)
DV97	n	n	n	n	n	n	n	n		S4Level 6 [7:0]	SV_LENS monitor level 6 (lower)
DV98	0	0	0	0	n	n	n	n		S4Level 7 [11:8]	SV_LENS monitor level 7 (upper)
DV99	n	n	n	n	n	n	n	n		S4Level 7 [7:0]	SV_LENS monitor level 7 (lower)
DV100	0	0	0	0	n	n	n	n		S4Level 8 [11:8]	SV_LENS monitor level 8 (upper)
DV101	n	n	n	n	n	n	n	n		S4Level 8 [7:0]	SV_LENS monitor level 8 (lower)
DV102	n	n	n	n	n	n	n	n		Total Start counts [15:8]	The counter values reported are collected during one of the slots 0 to 7. The slot number is determined by the lower 3 bits of the Base counter (DV37, Base counter [2:0]). These counters may be 0 if HV is off.
DV103	n	n	n	n	n	n	n	n		Total Start counts [7:0]	
DV104	n	n	n	n	n	n	n	n		Total Stop counts [15:8]	
DV105	n	n	n	n	n	n	n	n		Total Stop counts [7:0]	
DV106	n	n	n	n	n	n	n	n		Total Coincidence counts [15:8]	
DV107	n	n	n	n	n	n	n	n		Total Coincidence counts [7:0]	
DV108	n	n	n	n	n	n	n	n		Cal mode1	All 6 CP values of most recently sent Cal_mode command.
DV109	n	n	n	n	n	n	n	n		Cal mode2	
DV110	n	n	n	n	n	n	n	n		Cal timing1	

	B7	B6	B5	B4	B3	B2	B1	B0	Hex	Description	Note
DV111	n	n	n	n	n	n	n	n		Cal timing2	
DV112	n	n	n	n	n	n	n	n		Cal timing3	
DV113	n	n	n	n	n	n	n	n		Cal timing4	
DV114	n	n	n	n	n	n	n	n		HV_Main reference [7:0]	Last programmed reference value
DV115	n	n	n	n	n	n	n	n		HV_StartMCP reference [7:0]	Last programmed reference value
DV116	n	n	n	n	n	n	n	n		HV_StopMCP reference [7:0]	Last programmed reference value
DV117	n	n	n	n	n	n	n	n		HV_TOF [7:0]	Last programmed reference value
DV118	0	0	0	0	n	n	n	n		HV_Def [11:8]	Last programmed reference value
DV119	n	n	n	n	n	n	n	n		HV_Def [7:0]	Last programmed reference value
…											
DV125									0x00		remainder of packet is filled with 0x00 padding values

Table 19 Engineering mode packet layout

Note:
If the sensor is placed in engineering mode, formats DV38 to DV101 will contain monitor values only for packets sent where energy step = 0. In packets with energy step 1 to 7, DV38 to DV101 will be replaced by padding (0x0ff) due to timing limitations on the Sensor FPGA. This means that in engineering mode, SV monitor values are only available every 250ms. All other DV elements are valid independent of energy step number.

No padding of DV38 to DV101 occurs in the subcommutated HK stream or in engineering packets, requested by commands while the sensor is in another mode than engineering mode.

8.7 Tables in CENA

The only parts to be reprogrammed in CENA are the SV tables. The following 16 rewritable sets of 4 tables with 8 entries each are present:

- 1 set of SV zero tables (table ID 0), contains always zero values = 1 x 4 x 8 x 12 bit = 384 bits
- 15 sets of SV tables for normal operation, (table IDs 2 to 15) =15 x 4 x 8 x 12bit = 5760 bits

Predefined SV table values are either stored in EEPROM or in PROM, copied to DPU RAM at sensor initialization and transferred to the sensor at startup, with the possibility to change the tables prior to switching the sensor on. Afterwards, SV tables might be updated anytime using a Telemetry Command (though this will be rarely, within intervals of days or weeks). Updates to SV tables should be sent to the sensor immediately. They will be used in CENA upon reception of the next clock pulse. The SV table currently used by the sensor cannot be overwritten.

Note that the SV has a main power supply which is controlled by the DPU. It's voltage is constant until altered by the DPU (e.g. sensor startup or shutdown). The sweeping of the SV voltages is made internally in the sensor and based on the values of the SV tables by using the main power supply as a source.

Note: The same SV index is used to select the active table of SV_WAVE1, SV_WAVE2A, SV_WABE2B and SV_LENS. The Table select command (0x0A) in Table 17 allows selection of a different index for each table which has never been used before. The same index is always used for all four tables.

9 DPU COMMAND HANDLING REQUIREMENTS

9.1 Overview

All CENA related software in the DPU must be fully reprogrammable and patchable. For a summary of reprogrammable tables required on the DPU (see Section 10).

The DPU is required to handle the following Telemetry Command types:

- Real Time Command - the command should be executed immediately
- Time Tagged Command - the command should be executed at a specified time
- Macro Command - a sequence of Real-Time and/or Time-Tagged commands for immediate or later execution

The following Telemetry Commands need to be implemented:

Commands related to initialization of CENA
a) CENA turn on/off
b) CENA SV tables initialization from pre-programmed ROM-tables
c) Automatic initialization of the CENA sensor and sensor settings (observation mode, discrimination level, dead time, SV sweep tables, …), including HVPS settings. The DPU contains two (2) selectable sets with sensor initialization data.

Direct CENA programming
d) Direct programming of the CENA sensor using encapsulated sensor commands
e) CENA table rewriting commands

Commands related to processing of data in the DPU:
f) Set number of bins (mass, energy, incoming direction)
g) Set accumulation time
h) Select telemetry mode, set parameters for telemetry mode, e.g. reporting interval for non-coincidence data in counter mode
i) Data compression enable/disable, set parameters for compression scheme, e.g. bias b for logarithmic compression, possible parameters for rice compression
j) Energy table and look-up table selection
k) DPU table rewriting commands (SVM, SVE, LT, TT, MT, and other lookup tables)
l) Look-up table readout for verification
m) SV table readout for verification

Health check and related commands
n) Upon sensor start-up
o) By a Telemetry Command requesting an immediate health check
p) Automatically at programmed intervals

Housekeeping related commands
q) Set housekeeping reporting interval

The DPU must perform its own error checking of the telemetry commands received from S/C. A minimum is to verify the length of the telemetry commands and telemetry command checksums. This error checking should not try to interpret the encapsulated sensor commands that are sent to CENA and not make use of the checksum of the sensor command (an own checksum is required).

The DPU must keep track of the commands received for CENA by two counters, e g number of received and rejected commands:

- When DPU receives command, the command counter is incremented.
- When DPU receives command with an error such as wrong checksum, wrong length or undefined commands, the reject counter is incremented.

The DPU must be able to recognize errors such as length, Checksum of TC, etc. in the telemetry commands. It does not need to recognize errors in sensor commands such as checksums. Erroneous sensor commands will set the error flag in CENA which will be reported back to the DPU in HK.

Using this encapsulation, no modification of the DPU software will be required for additional sensor commands.

9.2 Direct CENA programming

A Telemetry Command is required that contains in its data portion a Sensor Command to be sent directly to CENA without further processing in the DPU. This will allow direct programming of CENA from ground.

9.3 Macro commands

A Macro command is a sequence of Real-Time and/or Time-Tagged commands for immediate or later execution. The following functionality is required:

- Upload and execution of Macro Commands
- Readout of stored Macro Commands for verification

9.4 Health check

CENA Sensor health check shall be performed from the DPU as follows:

1) Upon sensor startup (*)
2) By a Telemetry Command requesting a immediate health check
3) Automatically in programmed intervals e.g. 256 s, 1024 s, 4096 s (default), 16384 s, OFF

(*) If an error is detected, the initialization sequence should be stopped. The DPU should send the initialization status (OK, NG, location where the error occoured, etc.) to ground

For health check, DPU sets the sensor to Engineering Mode and also changes itself to Non-Process Mode for one 4 second clock period to obtain detailed internal sensor status. Also, as part of the health check the SV tables should be read back from IFE RAM and reported. No science data is collected during the health check. After completing the health check, the sensor should resume measurements with the same sensor and telemetry mode prior to when the health check was started.

9.5 Housekeeping

9.5.1 Obtaining Housekeeping from the sensor

Housekeeping data is sent in sub commutated form (one byte HK per data packet) together with the normal sensor data. The data rate available in the sub commutated HK channel is 256 bits per second. The DPU reassemble this data stream to a complete engineering mode packet and send it to ground. One engineering packet is available every 4 seconds. HK data may be obtained more frequent by switching to engineering mode or by sending a request HK sensor command.

A sensor command is also required if SV_tables are requested, since these are not contained in the engineering packets. Upon reception of a HK sensor command, CENA will send the corresponding data to the DPU inbetween the automatically transmitted packets.

Prior to further processing, the following HK data related to CENA, but generated in the DPU, are appended to every reassembled sub commutated HK data from CENA:

- +12V CENA current monitor
- +5V, -12V, +12V, +3.3V voltage monitors
- Active data binning and compression scheme including parameters
- any other CENA related HK information measured by the DPU, e.g. temperatures or similar

The detailed layout of the HK datastream in different modes is shown in [RE3], decoding and interpretation of values in [RE4].

9.5.2 Housekeeping reporting in telemetry during comissioning

During commissioning a high bandwidth housekeeping scheme is used. 58 Bytes can be transferred in each 4 sec cycle splitt into 2 requests of 29 Bytes every 2 sec. See also [RE3] and [RE4].

Only parts of a full CENA HK packet are transferred. The following values out of a full HK packet need to be transferred:

Values (DVx from Table 19)	**Number of Bytes**
DV1 - DV11	11
DV18 - DV23	6
DV34-DV39	6
DV52-DV53	2
DV54-DV55	2
DV68-DV69	2
DV70-DV71	2
DV84-DV85	2
DV86-DV87	2
DV100-DV101	2
DV102-DV107	6
DV114-DV116	3
DPU measured voltages and currents	7
DPU HK	2
Total without headers	**55**

Table 20 CENA commissioning HK data

9.5.3 Housekeeping reporting during nominal operations

Because of the sharing of HK bandwidth between SWIM and CENA, the following explanation covers both sensors. For more details about the terminology used for SWIM see SWIM SICD [RE2]. See also [RE3] and [RE4].

All available HK data values of both sensors are then concatenated to a list as shown below.

Description		Source of data	Size [Bytes]
CENA HK data			
	Values from subcommutated HK data stream	Values DV1 to DV119 from Table 19.	119
SWIM HK data			
	Current SWIM HK data	HK0 ..HK6 and HK11 od SWIM HK parameters (12 bit wide, in packed form) as described in the SWM SICD Section "12.4.2 HK parameters",	11
DPU HK			
	Currents and voltages measured by DPU related HK	5 voltages, 2 currents,.	7
	DPU HK	Flags	2
Total			136 (*)

Table 21 Combined SAS HK list

(*) this is without header bytes.

136 Bytes are divided in 4 packets, 34 Bytes each without header. One packet is transmitted every 32 sec resulting in a reporting frequency for all individual HK values of 128 sec. See also [RE3] and [RE4].

9.6 High Voltage commanding

See Sections 8.4.1 and 8.4.5 for additional constraints when performing HV commanding.

9.6.1 Switching on and increasing

The command sequence for switching HV on and increasing is:

- HV level set enable
- HV level set (at level 0)
- HV on enable (in space or in good vacuum only, if HV is installed)
- HV safety disable (in space or in good vacuum only, if HV is installed)
- HV on enable
- HV on
- HV level set enable
- HV level set at level 1
- HV level set enable
- HV level set at level 2
- ....

9.6.2 Decreasing and switching off

The command sequence for decreasing and switching off HV is:

- HV level set enable
- HV level set
- HV level set enable
- HV level set
- ....
- HV level set enable
- HV level set (at level 0)
- HV off

9.7 TDC test pulse generator commanding

The command (Cal mode) for setting the TDC test pulse generator can be found in Table 18. An example:

“0d b5 3c 00 00 02 02” (without length byte) will generate test pulse with:

- START SECTOR 4 (ID=3) at t=0
- START RING 2 (ID=1) at t= 0
- STOP MESH at t=250ns
- STOP SECTOR 5 (ID=4) at t=250ns
- Generation rate of 2.5kHz

Since the time interval of TOF is 1.953 ns; 250ns corresponds to TOF of 128 (=0x080). Using Table 3, coincidence event data will be 0x2d07f -- 0x2d081, when corresponding channels (Ch in Figure 3) are enabled and event data selection bitmask is set appropriately.

10 DPU DATA HANDLING REQUIREMENTS

10.1 Processing and reduction of data

DPU receives 12800 bits of data from CENA every 125 msec, which includes scientific and HK data. The contents of the scientific data change depending on the sensor mode. After receiving the data, DPU decodes and reformats both types of data. The format of the data is dependent on the telemetry mode. All telemetry data being transferred to the S/C must have timing information added. The time-tagging provide the acquisition time of the data.

10.2 Telemetry modes

The instrument has four telemetry modes which defines data format and a data processing before transmission to ground. The DPU processes the data collected from the sensor and generate data sets compatible with one of the four telemetry modes. The data sets are either down-linked to ground or stored into a temporary memory on the S/C side.

The modes are:

1. Mass Accumulation Mode
2. TOF Accumulation Mode
3. Count Accumulation Mode
4. Non Process Mode
5. Idle Mode

DPU can change the sensor mode anytime. When the DPU changes the sensor mode, the sensor changes its mode internally after the beginning of the next Sample period (4 s). This means that the format of the sensor data is not changed at the same as the command is issued.

To check the status of the sensor, health check is made approximately every hour (4096s). During health check, the DPU set the sensor to Engineering Mode and also change itself to Non-Process Mode for one Sample period, in order to obtain detailed internal sensor status.

10.3 Possible combinations of telemetry mode with sensor mode

Telemetry Mode	Sensor Mode
Mass Accumulation Mode	Coincidence Mode
TOF Accumulation Mode	Coincidence Mode
Count Accumulation Mode	Counter Mode
Non-Process Mode Idle Mode	Any Any

Table 22

10.4 Data accumulation

In Mass Accumulation Mode, TOF Accumulation Mode, and Count Accumulation Mode, memory in the DPU is allocated for count data accumulation. Data coming from the sensor is being sorted by look-up tables and is being summed up into two types of accumulation matrixes during a time period specified by commands:

A) The accumulation matrix has:

Contents:	event data integrated during a sampling period
Dimensions:	4 dimensions (E, P, C, M) for Mass Accumulation Mode,
	2 dimensions (E, TOF) for TOF Accumulation Mode,
	3 dimensions (E, P, X) for Count Accumulation Mode,

where E = energy group, C = channel group, P = phase group, M = mass group, TOF = time of flight, and X = type of counters, namely START ring, START sector, STOP plate, STOP mesh, START coincidence count (see 10.9, Count Accumulation Mode)

B) The accumulation scaling matrix has:

Contents:	counter data summed during a sampling period
Dimensions:	3 dimensions (E, P,Y) for Mass Accumulation Mode,
	2 dimensions (E,Y) for TOF Accumulation Mode,
	not needed for Count Accumulation Mode,

where Y is the type of counters, namely Total START count, Total STOP count and Coincidence STOP count.

Numbers of bins in each element can be set by commands. Possible numbers of bins are as follows:

n(C)	1 or 7
n(E)	1, 2, 4, or 8
n(P)	1, 2, 4, 8, 16, or 32
n(M)	1, 2, 4, 8, 16, 32, 64 or 128
n(TOF)	1024

where n(XX) means the number of bins for XX.

The numbers of bins in E and P are coupled and are not independent and as follows:

If n(E) = 1, 2 or 4	then n(P) = 1, 2, 4, 8, 16, or 32
If n(E) = 8	then n(P) = 1, 2, 4, 8 or 16

Important: The total number of elements in the accumulation matrix must not exceed 8192 due to memory space limitations. Any mode requiring a larger accumulation matrix is invalid.

10.5 Mass accumulation mode

This mode is used to obtain ENA data with mass information and will commonly be used in the orbit. This telemetry mode requires Coincidence Mode as a sensor mode. A coincidence data from the sensor is sorted and is accumulated into a matrix. The accumulation matrix has 4 dimensions, E (energy), C (channel), P (phase), and M (mass). An accumulation is being made during a specified time interval, which is defined by a command.

To compensate for high count rates, where not enough space is available to transmit all coincidence events, the total number of start, stop and coincidence stop counts is added up for each combination of n(P) and n(E) in the Accumulation Scaling matrix. This matrix will allow the scaling of the accumulation matrix during the data analysis on ground.

When Mass Accumulation Mode is set, Coincidence Mode is always needed as the sensor mode. In this case DPU receive event entries of coincidence counts in each energy step. DPU obtain its mass group (M), incoming direction (C), and energy (E) for every coincidence event and accumulates them into the accumulation matrix. This accumulation is being made over a certain time which is set by a command. Finally, DPU sends to S/C the contents of the accumulation matrix and other information after the accumulation.

The schematic data flow in Mass Accumulation Mode is shown in Figure 9. A mass group M is calculated from START ring, START sector, STOP plate and TOF by using look-up tables. The energy group E as well as the phase group P are calculated from the slot number of each sensor data packet. The channel group C corresponds directly to START sector.

For every event which is obtained, the DPU increment the counters specified by E, P, C and M in the Accumulation matrix. The numbers of bins for each parameter can be set by commands. The total counter data included in sensor data are accumulated in the Accumulation scaling matrix. This matrix only has two dimensions; energy group E and phase group P. On sending the data to S/C, information about HK and data acquisition time are also attached.

Data Contents:

- Accumulation matrix
- Accumulation scaling matrix
- Inhibit coincidence count
- Binning parameters
- 1 HK data packet
- Data acquisition time

Numbers of bins:

Channel step, C	n(C) = 1 or 7
Energy step, E	n(E) = 1, 2, 4 or 8, depending on P
Mass step, M	n(M) = 1, 2, 4, 8, 16, 32, 64 or 128
Phase step, P	n(P) = 1, 2, 4, 8, 16 or 32, depending on E

The product of n(C) * n(E) * n(M) * n(P) must not exceed 8192. Any mode with a larger product is invalid. The product of n(E) * n(P) can not be larger than 128 since there are only 128 slots in a Sample (4 s) cycle.

To facilitate the analysis of the science data, a complete CENA HK data packet must be appended to the data, together with the parameters used for binning and interval of data accumulation

10.6 Data processing method

Data processing for each event consists of five steps.

Step 1 Obtain index of Energy depending on sweep pattern

This index will later be used to obtain the 'real' value of the energy from the SVE-Table

Energy-index E-index = SVM-Table[SV-index, Energy-step]

The value for Energy-step is calculated out of the slot number of the packet as shown in 7.1.

Step 2 Obtain derived data for mass calculation by look-up tables

a) Sq. root of energy	En = SVE-Table[E-index]	(10 bit values)
b) Inv. of path length	L_-1 = LT[sector, ring, plate, E-index]	(12 bit values)
c) Flight time	t_1 = TT[tof, E-index]	(10 bit values)

The SVE-table returns the actual particle energy corresponding to an Energy-index. Consequently, the values returned from the SVM- and SVE- tables must reflect the particle energy selected in the SV tables sent to the sensor.

When changing the SV tables such that the selected particle energy changes, the SVM- and possibly the SVE-tables must be updated too by command. Note that there are 16 possible values for E-index that may be freely assigned to actual particle energies E.

Contents of the tables are rewritable in orbit by commands. Note that the Length-Table (LT) and the Time-Table (TT) are also used to validate signals. This means that a **zero value (0)** in the look-up tables indicates specific data pairs created by sensor malfunction, which should be excluded from further data processing. The total of the inhibited signals must be counted. In case of an inhibited event the processing stops here. All tables in this step are rewriteable in orbit using telecommands.

Step 3 Calculate mass

Mass calculation is done using 32 bit unsigned integer operations. The values of the tables in step 2 guarantee that no overflow occurs.

mass_0_5 = (((En* t_1 * L_-1) >> 16) * Factor) >> 16 Equation (1)

with Factor = 3340 **which must be adjustable.**

If the calculated value for (mass_0_5) is larger than 255 then a value of 255 must be assigned to (mass_0_5) prior further processing.

Note: The value calculated is actually proportional to the square root of the mass.

Step 4 Bin the data according to the binning parameters set

a) mass group	M = MT[mass_0_5] / {128/n(M)}	Equation (2)
b) channel group	C = sector / {7/n(C)}	Equation (3)
c) energy group	E = Energy_step modulo n(E)	Equation (4)
d) phase group	P = phase / {32/n(P)}	Equation (5)

Note that all divisions in 4b) to 4d) are integer divisions. Phase and Energy-step are defined in Section 7.1. The contents of the Mass-Table[MT] are rewritable in orbit by telecommands.

Step 5 Update the accumulation and the accumulation scaling matrix

a) is required for all events in a packet
Accumulation matrix (M, C, E, P) = Accumulation matrix (M, C, E, P) +1

b) is needed once after all events in a packet have been processed
Increment the three totalizing counters Y (Total START count, Total STOP count and Coincidence STOP count).
b) Accumulation scaling matrix (E, P,Y) = Accumulation matrix (E, P,Y) + value of counter Y

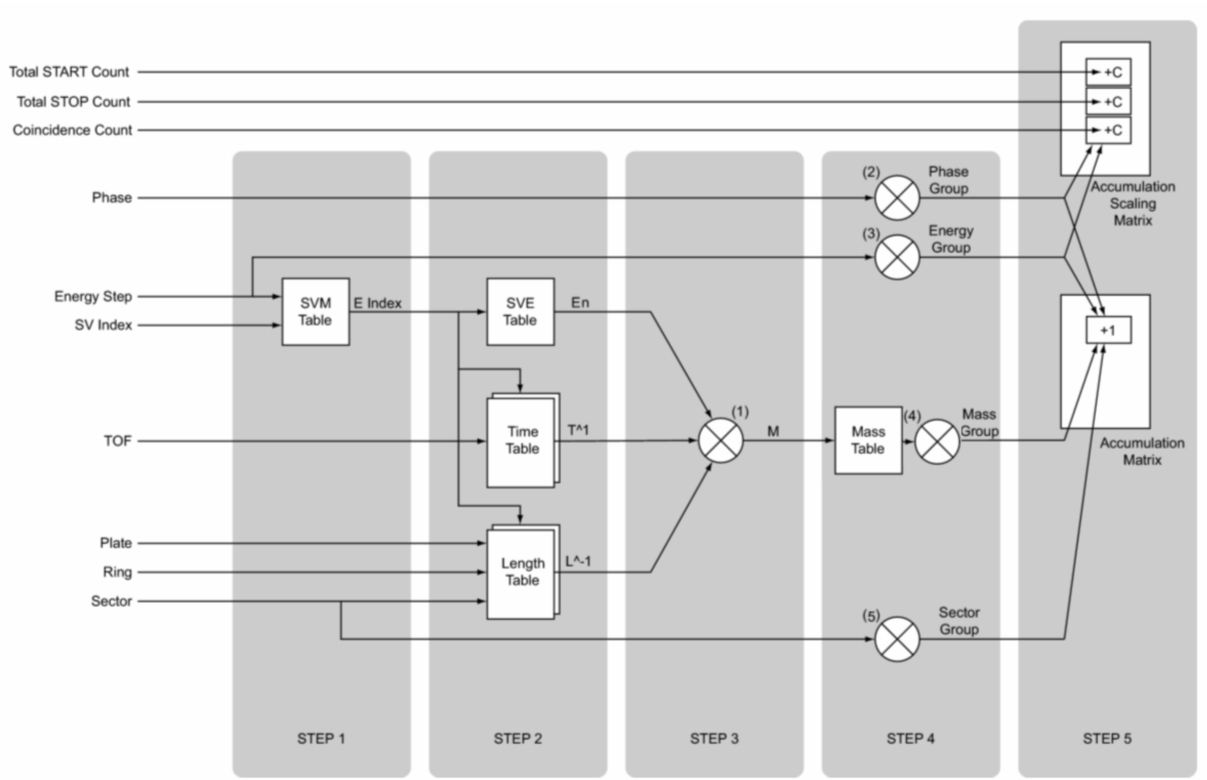


Figure 9

10.7 Updating of tables in DPU

The 5 data processing tables from Figure 9, namely SVM, SVE, Time, Length, and Mass tables are updated on demand by TC. An example for table content may be found in Reference [RE1]. Updating frequency may vary but will be in the order of once per week to months. During updates the sensor mode must be changed to Idle Mode (Section 10.11) to avoid usage of the tables that are being updated.

SVM table: This table needs to be changed when completely new SV tables are desired for CENA. The SVM table on the DPU needs to fit to the SV tables used on the sensor for successful data processing. Will be changed seldom.

SVE table: This table needs to be updated when a changed set of energy bin center energies is desired. The pre-programmed values are chosen such that an even coverage of the whole energy range is obtained. Note that this table does not need to be changed when the available center energies should be swept in a different order or pattern.

Time, Length and Mass tables:
These three tables contain calibration values related to the instrument geometry. Their values will be changed only seldom.

10.8 TOF accumulation mode

This mode is used to obtain raw TOF distributions without mass information. This mode is similar to Mass Accumulation Mode, except that TOF data is accumulated instead of mass data. In TOF Accumulation Mode, the mass is not calculated, and the raw TOF data is directly used for the accumulation instead of the mass. The accumulation matrix in this mode has 2 dimensions which are, E (energy) and T (TOF). DPU does not use the other parameters, P (phase) and C (channel). Since a TOF data has 10 bits, the number of TOF bins is always 1024.

Data Content

- Accumulation matrix
- Accumulation scaling matrix
- Binning parameters
- 1 HK data packet
- Data acquisition time

Numbers of bins

- Energy step, E n(E) = 1, 2, 4 or 8
- TOF step, T n(TOF) = 1024, always
- Phase, P n(P) = 1, always
- Channel, C n(C) = 1, always

To facilitate the analysis of the science data, a complete CENA HK data packet must be appended to the data, together with the parameters used for binning and interval of data accumulation.

10.9 Count accumulation mode

This mode is used to obtain detailed signal count at each MCP plate. This mode is similar to Mass Accumulation Mode, except that counter data are summed up.

When Count Accumulation Mode is set, the sensor always need to be set to Counter Mode. In this mode, instead of receiving coincidence events, DPU receive detailed total counts on each MCP anode during one energy step. Then the total count data are summed up the accumulation matrix. This accumulation is being made over a certain time which is set by a command, and then the contents of the accumulation matrix are sent to S/C.

The accumulation matrix used in the mode has three dimensions, E, P, and X, where X means types of counters. (See the contents of a data packet in Counter Mode.)

X consists of:

- START ring/sector 4x7 counters (each 16 bit)
- START ring 4 counters (each 16 bit)
- START sector 7 counters (each 16 bit)
- STOP plate 8 counters (each 16 bit)
- STOP mesh 1 counter (16 bit)
- START sector coincidence 7 counters (each 16 bit)

Data Contents:

- Accumulation matrix
- Binning parameters
- 1 HK data packet
- Data acquisition time

Numbers of bins:

- Energy step, E n(E) = 1, 2, 4 or 8 depending on P
- Phase step, P n(P) = 1, 2, 4, 8, 16 or 32 depending on E

To facilitate the analysis of the science data, a complete CENA HK data packet must be appended to the data, together with the parameters used for binning and interval of data accumulation.

10.9.1 Non-coincidence event data collection

With the sensor in Counter mode, non-coincidence event data is sent as part of the sensor data. Every nth Sample interval (4 sec), this data is aggregated for one 4 sec interval in a special buffer and sent to S/C. The events in the buffer need to be tagged with the slot number from which they originated.

The type of non-coincidence events reported by the sensor is selected by a 16 bit wide bitmask sent to the sensor (Param3 and Param4 of Observation mode set – Command, see Table 17). A complete event requires 4 signals; start ring, start sector, stop sector, stop mesh which resulte in 16 possible combinations of which 15 are incomplete events, hence a 16 bit wide mask.

The rate at which the non-coincidence buffer is reported to ground is determined by a telemetry command which has the value of N as parameters. Default value on the DPU for N is 0 (zero), indicating not to report non-coincidence events at all. Values > 0 will turn reporting on.

To keep science data rate low, N is 0 as default or at least 32 for reporting.

Data Contents:

- Non-coincidence event buffer
- 1 HK data packet

10.10 Non-process mode

This mode is used to obtain raw data from the sensor and is mainly used for sensor diagnostics. In Non-Process Mode, no data processing is made and data from the sensor is directly stored in a memory in the DPU, regardless of the sensor mode. Note that buffer overwrite (to erase unsent contents in the buffer) is not allowed in order to keep data continuity. Then the data stored in the buffer are sent to S/C.

Since the data rate from CENA to DPU is higher than S/C telemetry data rate, the buffer will be full with sensor data at a certain time. Buffer size must be sufficient to accumulate several 4 sec intervals. The data must be handled as follows:

A receive buffer in the DPU is filled by the data received from the sensor.

- Recording into this buffer starts at the next Sync pulse. When the receive buffer is full, recording stops and the content of the buffer are sent to ground. The buffer content is not automatically cleared after sending some of the content to S/C and new recording starts only when receiving a new ‘goto non process mode-TC’.

It must be possible to perform lossless compress of the data prior sending it to S/C. Lossless compression (enabled or disabled) must be selectable by telemetry command.

Data Contents:

- Buffer (stored with raw sensor data)
- 1 HK data packet
- Data acquisition time

To facilitate the analysis of the science data, a complete CENA HK data packet must be appended to the data, together with interval of data accumulation.

10.11 Idle mode

This mode is used to suppress sending science data to the S/C while the sensor is operating nominally (e g during eclipses). In this mode no science data is sent to the S/C but only HK data according to the settings in chapter 9.5. No data accumulation or binning takes place.

Data Contents:

- none

10.12 Data compression

Logarithmic compression is used to reduce the data size of the accumulation matrix and other accompanying counter data. The logarithmic compression shrinks 32, 16 or 12 bit data fields down to 8 bits. The following procedure is used:
C = compress(sub(**X**,b))

Where:

- X original data word (12 or 16 bit)
- C compressed value (8 bit)
- B bias value (12 or 16 bit, depending on original data word)
- sub(a,b) function returning 0 if a < b, and a-b otherwise
- compress(z) compression of z according to Table 23 and Table 25

The bias value b is 0 (zero) by default. It should be possible to change by telemetry command. Setting this value to 1 will reduce the noise floor in the produced data making Rice compression more efficient for noisy data at the extent of loosing some resolution for very low count rates.

Linear input code (32 bit)	**Compressed code (8 bit)**
00000000 00000000 00000000 000tuvwx	00 0tuvwx
00000000 00000000 00000000 001uvwxy	00 10uvwx
00000000 00000000 00000000 01uvwxya	00 110uvw
00000000 00000000 00000000 1uvwxyab	00 111uvw
00000000 00000000 00000001 uvwabcde	01 000uvw
00000000 00000000 0000001u vwabcdef	01 001uvw
00000000 00000000 000001uv wabcdefg	01 010uvw
00000000 00000000 00001uvw abcdefgh	01 011uvw
00000000 00000000 0001uvwa bcdefghj	01 100uvw
00000000 00000000 001uvwab cdefghij	01 101uvw
00000000 00000000 01uvwabc defghijk	01 110uvw
00000000 00000000 1uvwabcd efghijkl	01 111uvw
00000000 00000001 uvwabcde fghijklm	10 000uvw
00000000 0000001u vwabcdef ghijklmn	10 001uvw
00000000 000001uv wabcdefg hijklmno	10 010uvw
00000000 00001uvw abcdefgh ijklmnop	10 011uvw
00000000 0001uvwa bcdefghi jklmnopq	10 100uvw
00000000 001uvwab cdefghij klmnopqr	10 101uvw
00000000 01uvwabc defghijk lmnopqrs	10 110uvw
00000000 1uvwabcd efghijkl mnopqrst	10 111uvw
00000001 uvwabcde fghijklm nnnnnnnn	11 000uvw
0000001u vwabcdef ghijklmn nnnnnnnn	11 001uvw
000001uv wabcdefg hijklmno nnnnnnnn	11 010uvw
00001uvw abcdefgh ijklmnop nnnnnnnn	11 011uvw
0001uvwa bcdefghi jklmnopq nnnnnnnn	11 100uvw
001uvwab cdefghij klmnopqr nnnnnnnn	11 101uvw
01uvwabc defghijk lmnopqrs nnnnnnnn	11 110uvw
1uvwabcd efghijkl mnopqrst nnnnnnnn	11 111uvw

Table 23

Linear input code (16 bit)	Compressed code (8 bit)
00000000 000uvwxy	000uvwxy
00000000 001uvwxy	001uvwxy
00000000 01uvwxya	010uvwxy
00000000 1uvwxyab	011uvwxy
0000000*1* uvwxabcd	1000uvwx
0000001u vwxabcde	1001uvwx
000001uv wxabcdef	1010uvwx
00001uvw xabcdefg	1011uvwx
0001uvwx abcdefgh	1100uvwx
001uvwxa bcdefghi	1101uvwx
01uvwxab cdefghij	1110uvwx
1uvwxabc defghijk	1111uvwx

Table 24

Linear input code (12 bit)	Compressed code (8 bit)
0000 000uvwxy	000uvwxy
0000 001uvwxy	001uvwxy
0000 01uvwxya	010uvwxy
0000 1uvwxyab	011uvwxy
0001 uvwxyabc	100uvwxy
001u vwxyabcd	101uvwxy
01uv wxyabcde	110uvwxy
1uvw xyabcdef	111uvwxy

Table 25

After the logarithmic compression, lossless compression (e.g. RICE compression) is also applied to the data, which will be downlinked to ground. The lossless compression can be switched on and off by telemetry commands independent of sensor mode.

10.13 Memory requirement on DPU

Memory requirements for CENA in the DPU are designed to fit with the memory architecture on the DPU as shown in Figure 10. The total amount of RAM needed for CENA is well below the 6 MBit of the available CPU internal and external RAM.

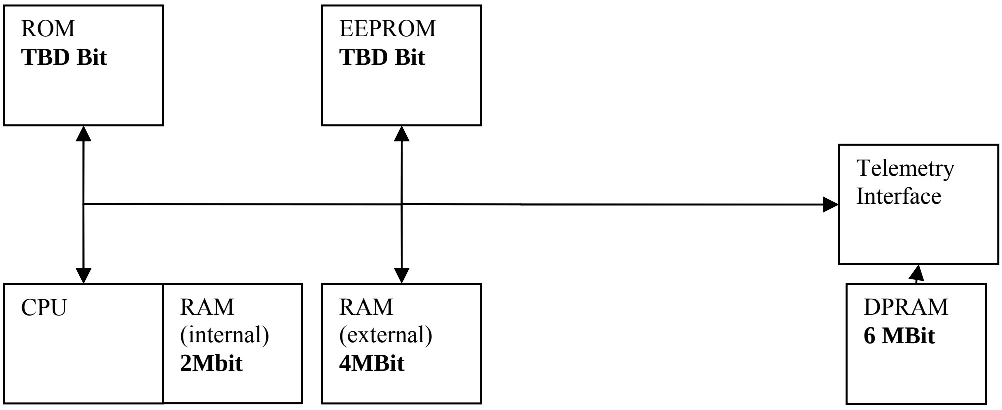


Figure 10

10.13.1 SV and Lookup tables

CENA SV and Lookup tables in DPU are required to be stored either in EEPROM or ROM. After sensor start they shall be copied to RAM. This, in order to ensure that they can be modified by Telemetry command. The following tables are needed.

Table type	Qty	Size	Total [bits]
SV	16	16 x 4 voltages x 8 energy steps x 12 bits	6.144
Lookup			
SVM	1	SV-index x energy step x 4 = 16 x 8 x 4	512
SVE	1	E-index x 16 = 16 x 16	256
LT	1	sector x ring x plate x E-index x 16 = 7 x 5 x 9 x 16 x 16	80.640
TT	1	TOF x E-index x 16 = 1024 x 16 x 16	262.144
MT	1	Mass x 8 = 1024 x 8	8.192
		Total of initialized lookup table memory	**357.888**
		The total amount of non-volatile ROM (or EEPROM) needed in DPU for CENA	**357.888**

Table 26

SV tables holds the current values sent to the sensor and may be overwritten by TC. See also section 0. Lookup tables are used for data processing in DPU. Mass accumulation mode.

10.13.2 Accumulation tables

Accumulation matrixes and Acc. Scaling matrixes reside entirely in RAM. The tables are initialized with zeroes and are used for data processing. Tables with the same group number are not needed at the same time.

Table type	Size	Total [bits]
Accumulation matrix in mass accumulation mode	n(E) x n(P) x n(C) x n(M) x 16 = 8 x 1 x 7 x 128 x 16	114.688
Accumulation scaling matrix in mass accumulation mode	3 x [n(E) x n(P)] x 16 = 3 x [128] x 16	6.144
	Total in mass accumulation mode	120.832
Accumulation matrix in TOF accumulation mode	n(E) x n(TOF) x 16 = 8 x 1024 x 16	131.072
Accumulation scaling matrix in TOF accumulation mode	n(E) x 16 = 8 x 16	128
	Total in TOF accumulation mode	131.200
Accumulation matrix for count accumulation mode	[n(E) x n(P)] x counters = [128] x 55 x 16	112.640
	Total in count accumulation mode	112.640
	Maximum of accumulation matrix memory at a given moment	**131.200**

Table 27

10.13.3 Buffers

Buffers are used to store raw data or event data from the sensor in various configurations. These tables are not needed at the same time.

Table type	Size	Total [bits]
Buffer to store 4 seconds of raw sensor data	slots x packet size = 128 x 3200	409.600
Buffer to store raw events in Counter mode	max events per slot x slot x 20 = 114 x 128 x 20	291.840
Buffer for 12.8 sec packed engineering mode data	packets per sec x sec x net packet size = 32 x 12.8 x 1000	409.600
	Maximum of special buffer memory	**409.600**

Table 28

10.13.4 Total RAM

Total amount of RAM needed in the DPU for CENA is estimated as follows: twice the accumulation matrix memory (to allow binning to continue with the other copy of the matrix while data is processed) + lookup table memory + plus special buffers = 2 x 128 K + 349 K + 400 K = **1005 Kbits.**

In Engineering Mode or in Non-Process Mode the special buffer area is used to buffer sensor data. In engineering mode, this will allow for approx. 12.8 seconds of buffering of engineering mode packets if only the data part (1000 bits per packet) is stored.

In non-process mode it will allow for buffering of 4 seconds raw data at 100kbps from CENA. Data buffering stops when the buffer is full (no data is overwritten) and data is sent to S/C. New buffering of data resumes on command or after a selectable interval as soon all data is sent to S/C.

11 TELEMETRY REQUIREMENTS

Here, only Mass Accumulation Mode is mentioned because that mode will be normally used in operation. The raw data production rate in this mode depends on the numbers of bins for parameters namely; C, P, E, and M and does also depend on the integration time. The integration is made in units of 4 seconds (Sync interval).

The raw data rate can be calculated by: r [bps] = n(C) x n(E) x n(M) x n(P) x a [bit] / (T x 4 [sec]), where a is a number of bits needed for each counter and is assumed to be 8 bits reduced from 16 bits by using logarithmic compression. T is a number of Sync pulses used for the accumulation. T = 1, 2, … , corresponding to accumulation during 4 seconds, 8 seconds ..., respectively.

As an example, raw data production rates are shown below for frequently used parameter settings in Mass accumulation mode without compression applied. Note that modes with bit rates >2 Kbps will very likely have T > 1 because of the large number of accumulation bins in these cases. T must be selected such that average bit rates >20kbps, including headers and HK, does not occur.

Observation	Parameter Setting	Bit rate [Kbps]
Global Imaging	n(C)=7, n(E)=4, n(M)=8, n(P)=1	0.51/T
	n(C)=7, n(E)=4, n(M)=8, n(P)=32	14.4/T
Detailed Mass Analysis	n(C)=1, n(E)=4, n(M)=128, n(P)=1	1.1/T
	n(C)=1, n(E)=4, n(M)=128, n(P)=32	32.8/T

Table 29 Data rate examples

The integration duration T directly corresponds to time resolution of measurement and will be selected in terms of scientific objectives.

In addition, a time stamp and HK data are added to the scientific data. Lossless compression can also be applied on the telemetry data.

If data production is too high and compression is not efficient enough to limit the data flow to 20kbps, the DPU should buffer the data. If the buffer is full the DPU can stop the transfer (buffering) of the residual data until buffer space is available again. Since the time resolution is important for measurements, buffering in DPU RAM provide the possibility to obtain continuous data flow in certain time periods, which is of course limited by the size of available DPU RAM.

12 LIST OF ACRONYMS

bps	bits per second
CENA	Chandrayaan-1 Energetic Neutrals Analyzer
CPU	Central Processing Unit
DPU	Digital Processing Unit
CT	Command Type
CP	Command Parameter
DT	Data Type
DV	Data Value
EIU	Experiment Interface Unit
HK	House Keeping
HV	High Voltage
IFE	InterFace Electronics
LENA	Low Energy Neutral Atom
LT	Length look-up Table
MCP	Micro Channel Plate
MT	Mass look-up Table
PDU	Power Distribution Unit
PS	Power Supply
S/C	SpaceCraft
SC	Sensor Command
SD	Sensor Data
SIU	Spacecraft Interface Unit
SV	Sweep Voltage table (on CENA and DPU)
SVE	Sweep Voltage Energy table (on DPU only)
SVM	Sweep Voltage Mapping table (on DPU only)
SWIM	Solar Wind Monitor
TBC	To Be Confirmed
TBD	To Be Defined
TBR	To Be Reviewed
TC	Telemetry Command
TD	Telemetry Data
TDC	Time to Digital Converter
TI	Time Indicator
TOF	Time Of Flight
TT	Time look-up Table