Onboard Software Document

FOR

CZT Imager Processing Electronics -ASTROSAT

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Definitions, Acronyms and abbreviations

CZTI	- Cadmium Zinc Telluride Imager
CPM	- Charge Particle Monitor
LAXPC	- Large Area Xenon Proportional Counter
SAA	- South Atlantic Anomaly
PE	- Processing Electronics
FPGA	- Field Programmable Gate Array
RAM	- Random Access Memory
EEPROM	- Electrically Erasable and Programmable ROM
DSP	- Digital Signal Processor
FEB	- Front End Board
SSR	- Solid State Recorder
BDH	- Base band Data Handler
BMU TC	- Bus Management Unit Tele-command
BMU TM	- Bus Management Unit Telemetry
LVDS	- Low Voltage Differential Signal
HBT	- High Bit rate Telemetry
LBT	- Low Bit rate Telemetry
CMND	- Command
I/F	- Interface
I/O or Io	- Input/Output
PPM	- Pulse per Minute

1 INTRODUCTION

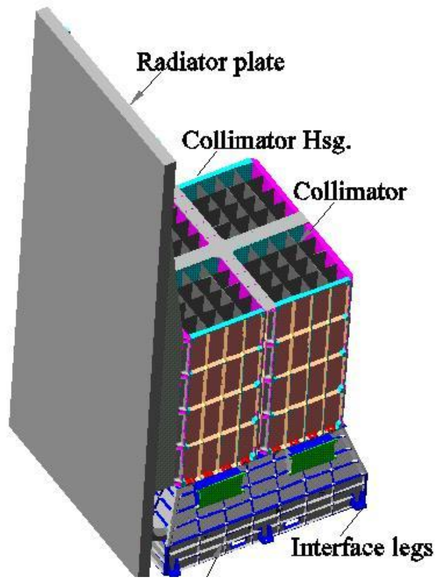


Figure 1. Cadmium Zinc Telluride (CZT) – Imager

The Cadmium Zinc Telluride (CZT) – Imager is the one among the four X-ray instruments on board ASTROSAT which covers the broad energy band extending from 0.3keV to 100keV. The characteristics of CZT-Imager are given in Table 1.The payload can be broadly be classified into two segments. The detector box and the processing electronics (PE).

The detector box contains 64 numbers of CZT modules of area 16cm^2 each there by achieving a detection area of 1024 cm^2. These modules are procured from M/s Orbotech Medical Solutions, Israel and they have their own individual electronics in the form of in-built ASICs. For redundancy, these 64 modules are arranged in four identical and independent quadrants each containing 16 detector modules. Each quadrant has power and digital (data and command) interfaces to the PE and it has its own intelligence to function as an independent unit. A CsI (Tl) detector just below the quadrants is used to have active background rejection and an alpha-tagged X-ray source is used for calibration of the payload. The processor on each quadrant independently communicates with each of the 16 detectors to collect the x-ray events and packetizes them by time tagging each event and correlating them with the background and calibration information. Experimental settings can be commanded from the ground through processing electronics.

The processing electronics is the interface between the detector quadrants and the satellite. The satellite interfaces like power, the low bit rate telemetry (TM), the tele-command (TC) and the pulse commands through the Bus Management Unit (BMU), high bit-rate telemetry through Baseband Data Handler (BDH) are routed through the Processing electronics (PE) box. Interfaces with other subsystems in the satellite mission like the Charge Particle Monitor (CPM) and LAXPC are also handled by PE. The schematic block diagram of CZT-Imager is shown in Figure 2.

Table 1: Characteristics of CZT-Imager

Area	1024cm ^{2}
Pixels	16384 (64 modules of 256 pixels each)
Pixel size	2.5mm x 2.5mm (5mm thick)
Read-out	ASIC based (2 ASICs per module)
Imaging method	Coded Aperture Mask (CAM)
Field of View	17^o x 17^o (> 100keV) 6^o x 6^o (10 – 100keV)
Angular resolution	~ 8arcmin (21arcmin geometric)
Energy resolution	~ 8% @ 100keV
Energy range	10 – 100keV Upto 1MeV (Photometric)
Sensitivity	0.5mCrab (5 sigma; 10^4 s)
Memory	50Mbytes per orbit
Command	32 bit data command 15 Pulse commands

2 Description of the Processing electronics

CZT-Processing Electronics (CZT-PE) is the main processing unit of the CZT Imager and it acts as an interface between the satellite and the four detector quadrants of the payload.

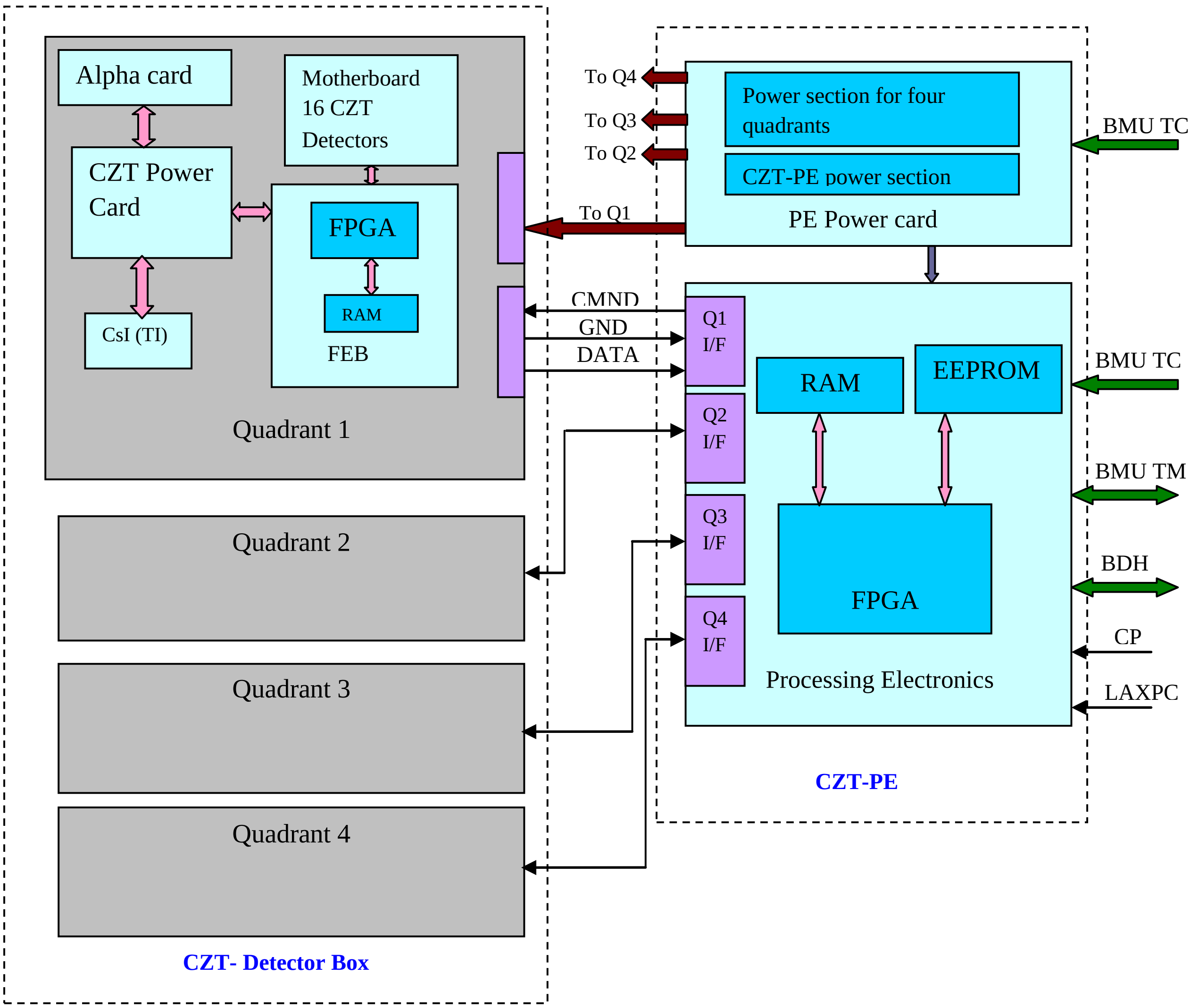


Figure 2. Block diagram of CZT-Imager

The PE consists of field programmable gate array (FPGA) which has the basic control logic, interface logic, memory access logic, a 16 bit fixed point DSP; a 2Mbits SRAM; an EEPROM (128k x 8) which acts as the boot memory for the DSP, power-on circuits as well as various interface circuitry. Two such sections exist.The PE power card is an integral section of the processing electronics package which supplies 5VDC and 2.5VDC required by the processing electronics card. The 28VDC-42VDC input to the power card is provided by the raw bus of the satellite. The power card also routes the raw bus and 5VDC to the detector quadrants' CZT power card. The ON/OFF control and selection of PE section and the detector quadrants are performed using pulse commands from BMU. There are 15 pulse commands to control the power supply at various stages. A maximum of 70W of power is allocated to the CZT-Imager of which each quadrant consumes 14W of power and PE package consumes 3W.

The interface circuits are common to both the sections of the processing electronics. BMU Tele-command interface, realized using CD4050 buffers, is used for receiving the tele-commands (32 bit) from satellite. There are 2 links for redundancy. Some of the tele-commands are used in PE for setting various parameters, while commands to the detector quadrants are sent to the respective quadrants.

RAM holds the detector data, LBT bytes, HBT packets, status words along with the temporary data used for preparing the LBT & HBT data. PE reads detector data through the detector interface (54HC244 buffer) every 1-sec, analyzes it, arranges it in a predefined frame format corresponding to the current mode of operation and stores/transfers data in the form of 1024-word packets to the satellite BDH via data formatter. There is one detector interface for each section.

BMU telemetry interface is used for transmitting the house keeping data. BDH interface , a Low Voltage differential signaling (LVDS) interface, is used for transmitting High bit rate Telemetry data. There are two BDH interfaces. Detector data ,each packet of 1024 words ,is packetized , written to PE onboard memory and is sent periodically, typically in 21ms intervals, to the solid state recorder (SSR) via a data formatter at 2MHz clock rate. The only response from the data formatter is a memory full status which is asserted when the memory is full. In such an event, the PE stops sending packets to BDH and stores the data packets in its memory. Various memory management schemes are adopted for efficient utilization of the PE memory.

EEPROM holds four versions of processing electronics software and various other detector module parameters. Any of these versions can be loaded by selecting the appropriate boot page. There is a provision to download the contents of any page of EEPROM for verification. On board programming of EEPROM through tele-commands is also possible, thereby facilitating the editing of onboard software.

PE also receives signals from CPM and LAXPC payloads. CPM SAA signal will alert the PE about possible damage to the detectors, due to high energy particles, during the passage of the satellite through the SAA region. In this region, high voltage circuits are switched off to protect the detectors from potential damage. LAXPC signal is a timing signal of 1ms duration, received every 16 seconds. It is used for synchronization. PE generates a 40-bit time stamp from the system time at the instant of receipt of the LAXPC pulse and this time stamp is sent through LBT and HBT data.

The DSP software will be booted to the RAM from the selected page of EEPROM on power on reset/reset release command/watchdog reset. Initialization command is to be given to initialize the detectors in all four quadrants. When Initialization command is received, On board software issues reset release commands to all detectors of the commanded quadrant, and each module will be taken to event mode serially. Onboard software monitors the second boundary and asserts the second flag which will issue second command to all detector quadrants. The detector data buffer flag is also toggled to indicate the buffer where the detector data read in that second is written to. Data written in the previous second is read from the alternate buffer for processing.

2.1 <u>Interface Details</u>

Tele-command Interface

Interface	: Serial, CD4050 CMOS buffered & CD4093 NAND Schmitt
Type of commands	: Mode setting commands Detector Commands
Signals	: Command, Clock (8 kHz) and transfer pulse

Telemetry Interface

Interface : Serial , CD4050 CMOS buffered
Signals : Address, ALE, PS, Clock (40 kHz) and Data

Detector Interface
Interface : Similar to RS-232 , 54HC244 buffered
Signals : Command and data
CPM
Signals : SAA level signal , CD4050 CMOS buffered
LAXPC Interface
Signals : LAXPC timing signal , CD4050 CMOS buffered
BDH Interface
Interface : Serial , LVDS buffered
Signals : Data, Clock (2MHz), Slot envelope
Memory Full from SSR

Interface between FPGA and DSP core : Input Output ports

Port	Output ports	Input ports
0	Q1 command (15:0)	Q1 error Bit, data count (13,12:0) EB0, DCNT0
1	Q2 command (15:0)	Q2 error Bit, data count (13,12:0) EB1, DCNT1
2	Q3 command (15:0)	Q3 error Bit, data count (13,12:0) EB2, DCNT2
3	Q4 command (15:0)	Q4 error Bit, data count (13,12:0) EB3, DCNT3
4	Q command (15:0)	Command LW (15:0)
5	Watchdog (15:0)	Command UW (15:0)
6	Read Packet Number (9:0)	LAXPC time offset (15:0)
7	Command Control Bit(0)	ECC error count (3:0)
8	Second flag (0)	Status (15:0)
9	Detector Data Buffer flag (0)	-

Status port (Input Port 8) description

S. No.,	Bit position	Description
1	15	LX: LAXPC pulse
2	14	SID : Section ID
3	13 :9	WDC: Watch dog reset count
4	8	ECB : ECC control Bit
5	7	WCB : Watch dog control Bit
6	6 :5	BP: boot page number
7	4	MF2 : Memory full status, BDH-R
8	3	MF1 : Memory full status, BDH-P
9	2	CPM : SAA status
10	1	CRS : Command receive link (BMU1/BMU2)
11	0	CSM [1] : Command receive

3 Basic functions of the Processing Electronics

The functions of the Processing electronics are distributed between the data handling logic implemented in the FPGA and onboard software of the DSP core. The complete operation starts after the reset release of PE which loads the onboard software from the EEPROM to RAM and initializes the functioning of the DSP core. The data interaction between the two segments is enabled using input/output ports.

Processing Electronics performs the following functions

- Acquisition of data from four detector quadrants
- Packetisation of data based on mode of operation
- Preparation of housekeeping data
- Sending packetized data with header in a specific frame format to BDH
- Handling of interface with Detector quadrants, CPM, LAXPC, BMU and BDH.

PE onboard software performs the following functions:

- Packetisation within every processing interval corresponding to the current mode of operation
- Preparation of LBT data
- Decoding and sending commands to detectors

- Decoding PE commands and initiation of necessary action
- Computation of LAXPC time stamp
- Measurement of detector temperature
- Memory management in the event of memory full signal from BDH
- HV control during passage of the satellite through SAA region

4 Detailed functional description of the Processing Electronics

The functions of the processing electronics are centered around the interfaces. The input interfaces to the system i.e the tele-commands from BMU, CPM level signal, memory full signal from the BDH decide the mode of operation of the system , modify the flags & status variables of the system. These parameters drive the major functions of the PE such as modifying the experimental setup , packetizing the detector data.

The functioning of the onboard software starts with Initialization which happens only once at the beginning of every reset release after which the software enters an infinite loop, termed as 'main loop', which is interrupted only by a reset command or power reset or watch dog reset. The DSP core architecture is provided with an interrupt which occurs every millisecond. The functions are further distributed between the interrupt sub routine and the main loop. The operations in the main loop are driven by the timing boundaries and status flags. The detailed description of each operation is sequentially described in this section.

Initialization :

As a part of system initialization two types of resets are handled ; power On reset and a watchdog reset. At the power on reset the following functions are performed: Initialization of I/O ports and enabling interrupt, Initialization of memory locations pertaining to LBT,HBT ,status words etc, Initialization of Quadrant status word locations. All variables are initialized as part of booting.

If reset is due to watchdog time out (which is evident from the non zero value of watchdog count in status port), the status variables and flags are loaded with their previous values. To facilitate this, the previous values of the variables should be stored in non initialized memory locations, allotted for this purpose every second. LBT and quadrant status words are also not initialized in the event of a watchdog reset. After initialization the main loop is entered.

List of experiment status variables are stored corresponding to veto HV status , Veto HV commanded status , CZT HV status , CZT HV commanded status , SAA selection logic , Shadow flag , reduced mode parameters , eeprom lock status.

Sl no:	Variable	Memory location
1.	Vhvflag	0x8600
2.	Vhvst	0x8601
3.	Czthvflag	0x8602
4.	Czthvst	0x8603
5.	Redflag	0x8604
6.	Shadowf	0x8605
7.	Ssl	0x8606
8.	saaf	0x8607
9.	Parrm pcnt Q0	0x8608
10.	Parrm pcnt Q1	0x8609
11.	Parrm pcnt Q2	0x860a
12.	Parrm pcnt Q3	0x860b
13.	Parrm vsd flag	0x860c
14.	Parrm 2wevrep flag	0x860d
15.	Parmf pcnt Q0	0x860e
16.	Parmf pcnt Q1	0x860f
17.	Parmf pcnt Q2	0x8610
18.	Parmf pcnt Q3	0x8611
19.	Parmf vsd flag	0x8612
20.	Parmf 2wevrep flag	0x8613
21.	mode	0x8614
22.	Eeplk	0x8615

Description of these variables are out of scope of this document.Refer to software design document for further information

Counters and Boundaries :

All timing operations on the onboard software are referenced using an interrupt which is generated every millisecond. A millisecond counter (Range 0-999) , a second counter(32 bit) is maintained in the software. The 32 bit second counter acts as system time. There are 3 prominent time boundary conditions apart from the millisecond boundary generated by the interrupt ; 21 millisecond boundary, Second boundary, 100 second boundary; which hold significance in the system and will be used in the remainder of the document. These boundaries are detected in the interrupt and corresponding flags are set.

Tele-commands :

32 bit tele-commands received from the satellite BMU is limited to a maximum of once in 2 seconds. Detection of a new command is done every millisecond. But the commands are decoded only in the second boundary. These tele-commands can be classified in to 2 types : PE related commands and detector commands. PE related commands are further classified in to 2 types : FPGA commands and the software commands.

The Detector commands are identified by the 0xC00Z in the upper word of the command, where Z: 0,2,4,6 for Quadrants 0..3 respectively and if Z:8 then the command corresponds to all detector. Depending on ‘Z’ the quadrant is identified and the Lower word of the command is forwarded to the corresponding quadrant and the quadrant status words are updated. The Quadrant commands which can be a part of Lower word of the tele-command is described below. These commands set the experimental parameters in the FEB and the detectors of each quadrant. The commands to be forwarded to the quadrants are put into a command buffer with 16 bit command and Quadrant map buffer after decoding the command in the main loop. These commands are actually sent to the quadrants in the ISR at the rate of one command per ISR i.e, one command per millisecond till the buffer is empty. Some important guidelines while sending commands to the detector quadrants are:

- Commands will be decoded and forwarded to Quadrants from the PE and Quadrant status words will be updated only if the Quadrants are ON.
- Quadrant is said to be ON if there has been data from the quadrant in reply to one second command consecutively for 2 seconds conversely if there is no data from the Quadrant even for one second it is considered OFF and the corresponding status variables and LBT locations are updated. This analysis is done in the ISR

- After Quadrant is powered ON the Quadrant Initialize command should be sent to PE on which PE sends a set of commands to reset release the detectors, set detectors in event mode, set the FEB in Event mode.

- HV commands has to be manually sent from the ground as a part of Quadrant Initialization. HV ON commands sent to the Quadrants will not be forwarded if the SAA flags are ON.

- Commands will not be forwarded to the Detectors from the FEB if the FEB is in command mode. So FEB & detector are to be taken to command mode in the same order to send commands to detector. Conversely detectors & FEB are taken to event mode in the same order to exit command mode and resume the operation of observing x-ray events.

- If commands to the quadrants are disabled (FPGA command) even the quadrant status variables are not updated in the onboard software.

Apart from the ground commands , PE also sends commands to the detector during HV handling ,temperature measurement , initialization etc.

The FPGA commands are used by the data handling logic of FPGA to configure the hardware aspects such as error correction, watch dog etc. They are identified by 0xC00A 00YY where YY: 0x00, 0x01, 0x20, 0x21, 0x30, 0x31, 0x40, 0x41. The significance of each command is described in the table below.

The Software Commands are used in the onboard software. The significance of each command is described in the table below.

S. No.,	**Command (32-Bit)**	**Name**	**Remarks**
Detector Commands (16 bit commands in XXXX are given in next table)			
1	0xC000 XXXX	CZTI Quadrant 1	XXXX represents 16-Bit command to Quadrant 1
2	0xC002 XXXX	CZTI Quadrant 2	XXXX represents 16-Bit command to Quadrant 2
3	0xC004 XXXX	CZTI Quadrant 3	XXXX represents 16-Bit command to Quadrant 3
4	0xC006 XXXX	CZTI Quadrant 4	XXXX represents 16-Bit command to Quadrant 4
5	0xC008 XXXX	CZTI All Quadrants	XXXX represents 16-Bit command to all Quadrants
FPGA Commands			
6	0xC00A 0000	CZTI Processor reset	Processor goes to reset mode
7	0xC00A 0001	CZTI Processor reset release	Processor reset is released
8	0xC00A 0020	CZTI PE to quadrant commands on	Commands to quadrants are enabled

S. No.,	Command (32-Bit)	Name	Remarks
9	0xC00A 0021	CZTI PE to quadrant commands off	Commands to quadrants are disabled
10	0xC00A 0030	CZTI ECC enable	Error correction check is enabled
11	0xC00A 0031	CZTI ECC disable	Error correction check is disabled
12	0xC00A 0040	CZTI watchdog reset enable	Watch dog reset is enabled
13	0xC00A 0041	CZTI watchdog reset disable	Watch dog reset is disabled
Software Commands			
14	0xC00A 005X	CZTI SAA entry/ exit	X represents 1 Bit 0: SAA exit 1: SAA entry
15	0xC00A 007X	CZTI shadow/ light	X represents 1 Bit 0: light 1: shadow
16	0xC00A 008X	CZTI SAA Selection logic	X represents 2 Bits 10: CPM 01: Command 11: both
17	0xC00B XXXX	Reduced mode command	XX represents 8 Bits. Lower nibble [3:0] : Quadrant selection

S. No.,	**Command (32-Bit)**	**Name**	**Remarks**
			Bit0: Quadrant 1 Bit1: Quadrant 2 Bit2: Quadrant 3 Bit3: Quadrant 4 **Next nibble [7:4]:** CZTI Number of packets ranging from 1 to 15 (value of the nibble changing from 0 to 7 correspondingly). **Bit 8:** CZTI Veto spectrum every second enable/ disable 1= Disable 0 = Enable **Bit 9:** CZTI Event 3 words/ 2 words 1 = 2 Words 0= 3 Words Bit 10: MF 0 : MF =0 1: MF=1
18	0xC02B 000X	Detector Quadrant Initialization	X represents 4 Bits. Lower nibble [3:0] : Quadrant selection Bit0: Quadrant 1 Bit1: Quadrant 2 Bit2: Quadrant 3 Bit3: Quadrant 4
19	0xC00C 00XX	CZTI EEPROM data write XX	XX represents 8-Bit data to be written into EEPROM

S. No.,	Command (32-Bit)	Name	Remarks
20	0xC00C 8000	CZTI EEPROM read, processor reset mode	EEPROM data read from the address specified by “C00E XXXX” command when processor in reset mode
21	0xC00D 800X	CZTI EEPROM lock	EEPROM can be locked with this command. X represents 4-Bit binary. (X+1)*12.8us is the time b/w writes.
22	0xC00D 801X	CZTI EEPROM unlock	EEPROM can be unlocked with this command. X represents 4-Bit binary. (X+1)*12.8us : time b/w writes
23	0xC00D 000X	CZTI EEPROM read by processor	EEPROM data is downloaded X represents 2-Bit binary X [1:0]: Bits to select one of the 4 EEPROM pages
24	0xC00D 001X	CZTI EEPROM boot page X	X [1:0]: Bits to select one of the 4 EEPROM pages. The selected boot page is booted to RAM from EEPROM on power-on-reset.
25	0xC00E XXXX	CZTI EEPROM address XXXX	17 Bits are address Bits to select the EEPROM memory location

Quadrant commands

S. No.,	Command (16-Bit)	Name	Remark
1	0x0100	CZT_command_mode	Set FPGA on FEB in command mode.
2	0x0101	CZT_event_mode	Set FPGA on FEB in event mode
3	0x02XX	CZT_EMRD_0_7	XX indicates 8 Bits. LS Bit is for 0^{th} detector and MS Bit is for 7^{th} detector. Bit =1 means data from that detector is not read. By default all are enabled.
4	0x03XX	CZT_EMRD_8_15.	XX indicates 8 Bits. LS Bit is for 8^{th} detector and MS Bit is for 15^{th} detector. Bit = 1 means data from that detector not be read. By default all are enabled.
5	0x040X	RAM select	X represents four binary Bits. Last 3 Bit combination is used for selecting any one of the 8 RAM partitions.
6	0x05XX	Veto LLD	00 to FF value is given for selecting LLD value of Veto detector. by default: 0x0528
7	0x060X	Veto HV	One LS Bit is used for switching on or off high voltage of Veto. 1-ON; 0-OFF
8	0x070X	CZT HV	One LS Bit is used for switching on or off high voltage of CZT. 1-ON; 0-OFF
9	0x0800	1_sec command	Not to be sent from ground
10	0x090X	CZT parity	X represents 4 Bit. LS Bit decides parity

S. No.,	Command (16-Bit)	Name	Remark
			0 - odd Parity 1- Even Parity by default - odd parity
11	0x0A0X	CZT reset/reset release	X represents four Bits 0000- All CZT detectors reset 0001- 0 to 7 detectors reset release/ 8 to 15 detectors reset 0010-8 to 15 detectors reset release/ 0 to 7 detectors reset 0011- all detectors reset release By default: All are in reset
12	0x0BXX	CZT ULD (LS 8-Bits)	XX (8 Bits) x 16 is the value Above which CZT events are ignored (default = 255)
13	0x0C0X	Veto spectrum range selection (LS 1-Bit)	X represents 1-Bit 0: veto spectrum range from 24 to 255 1: veto spectrum range from 0 to 231
14	0x11XX	T1 (LS 5-Bits)	CZT event report preparation by FEB FPGA after “T1” μsec Default: 1 Range: 1-15 (LS 5 Bits)
15	0x12XX	T2 (LS 5-Bits)	Alpha hold time after detection is “T2”μsec Default: 5 Range: 1 – 15 (LS 5 Bits)

S. No.,	Command (16-Bit)	Name	Remark
16	0x13XX	T3 (LS 7-Bits)	Time gap between two consecutive alpha pulses is "T3" µsec. Default: 20 Range : 10 – 100 (LS 7 Bits)
17	0x14XX	T4 (LS 5-Bits)	Veto hold time after detection is "T4" µs. Default: 5 Range: 1-20 (LS 5-Bits)
18	0x15XX	T5 (LS 7-Bits)	Time gap between consecutive veto pulses is T5 µs Default: 20 Range: 10 – 100 (LS 7-Bits)
19	0x16XX	T6 (LS 7-Bits)	Width of veto pulse is "T6" µs Default: 10 (LS 7-Bits) Range: 1 – 50.
20	0x17XX	T7 (LS 8-Bits)	Time gap between two consecutive veto pulses is (T7*8) µsec if the veto pulse width exceeds "T6" µsec. Default:496 Range: 10 – 1000 (LS 8-Bits)
21	0x8XXX	CZT data read/write command	

S. No.,	**Command (16-Bit)**	**Name**	**Remark**
	1000 ZZZZ CCCC CCCC	CZT Command	ZZZZ- represents CZT detector number CCCC CCCC-8 Bit CZT command
	1010 0000 0000 0000	CZT Data read	Data read command
	11DD DDDD DDDD DDDD	CZT Data write	All D’s represent data Bits, 14 Bit data can be sent

Interaction with the Detector Quadrants:

After power ON the detectors have to be initialized by sending a Quadrant Initialize command to PE. On receipt of this command PE sends the reads the Initialize commands list from the memory and sends it to the corresponding quadrant to put the quadrant in event mode for x-ray detection. The HV is also switched ON.The event data from each of the individual CZT detectors is polled by the FEB of each quadrant and stored in the RAM continuously. Only a max of 3072 events as 3 words per event can be captured in the FEB packet along with 24 words header and 232 words Veto spectrum. So a maximum of 9472 words can be obtained from each quadrant every second.The minimum number of 256 words will be surely be received if the FEB is in command mode or if there are no events. This data is packetized and sent to PE on receipt of a command commonly termed as 'one sec command'. PE sends this one second command to each quadrant at the Second boundary requesting for the event data pertaining to the previous second. The data handling logic in PE acquires the FEB data and writes it to the corresponding buffer. There are two buffers in PE memory corresponding to each quadrant. While data is written into one buffer by the data handling logic, the contents of the other buffer are read by PE software for packetisation at the second boundary.

The thermal cooling facility provided in the quadrants is intended to maintain the temperature of the detectors at 15^0C. So once in 100sec all detector temperatures are monitored and sent to the ground along with the SSM packets. The PE sends a sequence of 66 commands to the Quadrants simultaneously to for this purpose. These commands put the FEB in command mode then puts the FEB in command mode, sends command to read temperature, read the temperature value and change the detector to event mode. The temperature value of the 16 detectors is sent by the FEB in the 16 words allocated in the FEB header data. Temperature measurement is not initiated if the FEB is already in command mode. It has to be noted that once in 100sec the events monitoring will be stopped.

Commands for initialization of 16 detectors in each quadrant

No.	16 bit cmnd	Description	Remarks
1	0x0100	Command mode on for FPGA in FEB	
2	0x0a03	Reset release for all detectors	
3	0x8085	Event mode ON	Detector 0
4	0x8185	Event mode ON	Detector 1
5	0x8285	Event mode ON	Detector 2
6	0x8385	Event mode ON	Detector 3
7	0x8485	Event mode ON	Detector 4
8	0x8585	Event mode ON	Detector 5
9	0x8685	Event mode ON	Detector 6
10	0x8785	Event mode ON	Detector 7
11	0x8885	Event mode ON	Detector 8
12	0x8985	Event mode ON	Detector 9
13	0x8a85	Event mode ON	Detector 10
14	0x8b85	Event mode ON	Detector 11
15	0x8c85	Event mode ON	Detector 12
16	0x8d85	Event mode ON	Detector 13
17	0x8e85	Event mode ON	Detector 14
18	0x8f85	Event mode ON	Detector 15
19	0x0101	Event mode ON for FPGA in FEB	

Commands for detector temperature measurement

S. No.	Commands (16 Bit)	Description	Remarks
1	0x0100	Command mode on for FPGA in FEB	
2	0x8005	Command mode on	Detector 0
3	0x8105	Command mode on	Detector 1
4	0x8205	Command mode on	Detector 2
5	0x8305	Command mode on	Detector 3
6	0x8405	Command mode on	Detector 4
7	0x8505	Command mode on	Detector 5
8	0x8605	Command mode on	Detector 6

9	0x8705	Command mode on	Detector 7
10	0x8805	Command mode on	Detector 8
11	0x8905	Command mode on	Detector 9
12	0x8a05	Command mode on	Detector 10
13	0x8b05	Command mode on	Detector 11
14	0x8c05	Command mode on	Detector 12
15	0x8d05	Command mode on	Detector 13
16	0x8e05	Command mode on	Detector 14
17	0x8f05	Command mode on	Detector 15
18	0x809A	Temperature read command	Detector 0
19	0xA000	Read command for reading temp	
20	0x819A	Temperature read command	Detector 1
21	0xA000	Read command for reading the temp	
22	0x829A	Temperature read command	Detector 2
23	0xA000	Read command for reading the temp	
24	0x839A	Temperature read command	Detector 3
25	0xA000	Read command for reading the temp	
26	0x849A	Temperature read command	Detector 4
27	0xA000	Read command for reading the temp	
28	0x859A	Temperature read command	Detector 5
29	0xA000	Read command for reading the temp	
30	0x869A	Temperature read command	Detector 6
31	0xA000	Read command for reading the temp	
32	0x879A	Temperature read command	Detector 7
33	0xA000	Read command for reading the temp	
34	0x889A	Temperature read command	Detector 8
35	0xA000	Read command for reading the temp	
36	0x899A	Temperature read command	Detector 9
37	0xA000	Read command for reading the temp	
38	0x8a9A	Temperature read command	Detector 10
39	0xA000	Read command for reading the temp	
40	0x8b9A	Temperature read command	Detector 11
41	0xA000	Read command for reading the temp	
42	0x8c9A	Temperature read command	Detector 12
43	0xA000	Read command for reading the temp	

44	0x8d9A	Temperature read command	Detector 13
45	0xA000	Read command for reading the temp	
46	0x8e9A	Temperature read command	Detector 14
47	0xA000	Read command for reading the temp	
48	0x8f9A	Temperature read command	Detector 15
49	0xA000	Read command for reading the temp	
50	0x8005	Event Mode ON	Detector 0
51	0x8105	Event Mode ON	Detector 1
52	0x8205	Event Mode ON	Detector 2
53	0x8305	Event Mode ON	Detector 3
54	0x8405	Event Mode ON	Detector 4
55	0x8505	Event Mode ON	Detector 5
56	0x8605	Event Mode ON	Detector 6
57	0x8705	Event Mode ON	Detector 7
58	0x8805	Event Mode ON	Detector 8
59	0x8905	Event Mode ON	Detector 9
60	0x8a05	Event Mode ON	Detector 10
61	0x8b05	Event Mode ON	Detector 11
62	0x8c05	Event Mode ON	Detector 12
63	0x8d05	Event Mode ON	Detector 13
64	0x8e05	Event Mode ON	Detector 14
65	0x8f05	Event Mode ON	Detector 15
66	0x0101	Event mode ON for FPGA in FEB	

LBT data preparation:

LBT data consists 65 bytes of HK data from FEB and some general PE parameters which provides a diagnostic of the working of CZT Imager payload. In every second boundary, after reading the detector data PE writes the HK parameter from the detector data to the corresponding location in the LBT. The LBT location corresponding to the 5V monitor of each quadrant is zeroed when the quadrant is detected to be OFF in any second. Other LBT locations correspond to the PE parameters like last command received , second count , LAXPC time stamp and SYNC word.

Interface with CPM and LAXPC and HV control:

When the satellite enters the SAA region, CPM sends a level signal to the PE. The variable named SAA selection logic decides if the SAA condition is to be determined based on ground command or the state of the CPM signal or both. The SAA selection logic can be modified using ground commands. To avoid SAA entry/exit due to any false triggers on the CPM level signal, the CPM level is verified for consistency for 10 consecutive milliseconds before considering for SAA condition. In SAA entry, PE software sends commands to the detectors to switch Off the HV supplies. During the SAA region , requests for HV ON is held back and implemented after the satellite exits the SAA region. When the satellite exits the SAA region, PE software sends necessary commands to resume the appropriate state.

The LAXPC payload sends a 1ms pulse every 16 seconds to the PE for time synchronization. The software should compute the system time at the moment of receipt of LAXPC pulse and provide a 40 bit time stamp with 20 MS bits indicating second count, next ten bits indicating millisecond count and last ten bits indicating microsecond count. The LAXPC signal is detected in the ISR and time stamp is generated in the main loop. LAXPC time stamp is available in the LBT and in HBT frame headers.

HBT data packetization:

HBT packets are generated from the detector data continuously depending on mode of operation apart from the packets which are generated on receipt of ground commands The type of packet generated depends on the ground command received , mode of operation , memory level. The mode of operation is identified by a Mode ID in the header and the type of packet is identified by the Data ID. The packetized data is stored in allocated regions in memory. When a packet is written to memory, the Write Packet Number is incremented. Similarly, when a packet is read from memory, the read packet number is incremented. The difference between WPN and RPN gives the number of packets remaining to be read. If the memory full signal from BDH is low, PE software gives the current rpn to the corresponding output port. Accordingly, the packet is sent by the data handling unit to BDH and rpn is incremented by software. If memory full signal is high, rpn is not incremented and reduced modes of packet generation are initiated by PE based on the memory level. The parameters in reduced mode are selected through ground command.

5 Accumulation of Data:

The data from the detectors is received every second. Following data is prepared every second:

i) A mode count is prepared every second which gives the number of seconds, over a 100 second window, that was spent in each of the following states:

- Both HV On
- CZT HV Off
- Veto HV Off
- Both HV Off

This data is useful for analyzing the SSM data received in that hundred second boundary. These counts are stored in memory and are reset every 100-second when a fresh count is initiated. This data is sent along with SSM and header packet every 100-second.

ii) SSM data is prepared every second in the SSM buffer location allotted for each quadrant. At the 100-second boundary, command count, command history, status words, mode count and temperature data are loaded to the respective locations.

iii) Header data is prepared every second for 100-seconds in the header buffer location allotted for each quadrant. At the 100-second boundary, command count, command history, status words, mode count and temperature data are loaded to the respective locations. This data is used in SAA mode, shadow mode or when memory level is more than 1. This data is sent if, at any time, the detector quadrant was not in a 1sec mode over a 100-second window.

PE status words, which is a set of parameters related to the PE are prepared every hundred seconds. It is sent along with SSM and header packet or PE header packet every 100-second.

6 Mode of operation:

The mode of operation of individual detector quadrants defines the state of operation of the payload. The mode of operation is defined for each quadrant individually and will be deduced from the status of individual quadrant status or by the general processing electronics status or the ground commands based on the order of preference. The mode is selected in the each processing interval. The modes are chosen based on various input signals or through ground command. A description of the various modes of operation is given below.

The processing interval is the interval at the end of which the packets are sent , typically either 1s or 100s. If 100sec modes are encountered at any instant in the 100sec window then the corresponding packets are sent at the 100sec boundary.

Normal Mode (Mode ID: 0)

This is the default mode of operation of PE. Normal mode gets activated when PE is powered on and HVs are ON. The processing interval of this mode is one second and memory level is level 0. This mode has a data ID 0-3 corresponding to each quadrant.

SAA Mode (Mode ID: 9)

SAA mode of operation is selected when both CZT as well as Veto HVs of the particular quadrant are turned OFF due to ground commands or SAA entry. In this mode, header data of each second is extracted and compiled into one Quadrant header packet every 100s. If this mode is selected at any instant within a 100-second window, header packet of that 100-second will be sent at the 100-second boundary.

Shadow Mode (Mode ID: 10)

Shadow mode is chosen if the shadow entry command was sent from ground. In this mode, header data of a 100-second window is sent at the 100-second boundary. Frame/packet format is similar to SAA mode format. Thus, in this mode of operation, each frame contains only one packet. If this mode is selected at any instant within a 100-second window, header packet of that 100-second will be sent at the 100-second boundary.

Secondary Spectral Mode (Data ID: 8-11)

The secondary spectral mode runs in parallel with all the other modes. Software prepares the spectral data of each quadrant every second. The integrated spectra so prepared is packetized and sent to ground once in every 100 seconds. If PE was in SAA mode throughout the 100-second window then the SSM data of that period is not packetized. However, if at any instant, other modes of operation were entered into, SSM data will be packetized and sent at the 100-second boundary. If the level of memory is greater than level 2, the SSM data prepared is not packetized. This compressed data is sent to satellite every 100-second. Each frame contains two packets. SSM data of each quadrant is identified using a unique data ID (8-11).

Reduced Data Modes (Mode ID: 1-7)

Reduced mode can be entered into either by ground command or due to limited memory availability. The parameters for the command induced as well as memory level induced reduced modes can be set through a single ground command. When memory level is other than 0 or if the reduced mode flag (which can be set through tele-command) is asserted, PE switches to any of the reduced modes of operation as previously specified through ground command.

The processing interval of this mode is one second for modes 0-5 and 100-second for reduced mode 7. The following reduced modes of operation are available:

i) **Fixed No: of packets (Mode ID:4)**
PE generates a fixed number of packets from the data corresponding to each quadrant. The number of packets to be generated for each quadrant is also to be specified in the command send from the ground. Mode ID of this mode is 12. The frame format is similar to the normal mode format.

If the data count (number of words) from the quadrant (DCNT) is less than that accommodated in the number of packets specified, the actual data is read and packetized. To exit from command induced reduced mode, commanded number of packets should be 15.

ii) **Without Veto spectrum (Mode ID:1)**
PE generates packets without the Veto spectrum data (232 words).

iii) **Two word event report (Mode ID:2)**

PE generates packets with CZT event reports of 2 word length. When PE receives the event report data reduction command, onboard software reduces three word event reports to two word event reports and packetizes the data in the following format.

32-bit Event Report in Reduced mode 10:

D31-D23	D22-D14	D13-D6	D5	D4	D3-D0
Time (2.56 ms)	CZT energy	Pixel ID	Veto status	Alpha	Detector ID

Any combination of the three modes mentioned above (modes 9, 10 and 12) can be selected.

iv) **Header Data**

Header data in reduced mode is sent if the memory level is more than level 2. Only the FEB header and some required PE information is sent in this mode. To send this data, the header flag is set. Header data is identified using the unique data ID assigned to header packets from each quadrant (4-7).

PE header mode

This mode is entered into when all the detector quadrants are switched OFF. This mode can occur in the initial startup of the PE or at any time during the course of operation when all detectors are OFF. There is no detector data to be sent to ground, so PE status word and command history is sent in 1 packet. The processing Interval for this mode is 100-seconds. The packet is identified by data ID 16 in frame/ packet header. This mode is enabled if all quadrants were off throughout the 100 second window.

Mode ID	**Description**
0	Normal mode
1	Veto Spectrum Disable (VSD)
2	2W event report (2wevrep)
3	VSD+2wevrep
4	Fixed number of packets (fix pkt.)
5	Fix pkt. + VSD
6	Fixpkt.+2wevrep
7	Fixpkt.+2wevrep+VSD
8	-
9	SAA
10	Shadow
11	SAA + Shadow
12	Memory Management Level (mml) > 1
13	mml>1+SAA
14	mml>1+Shadow
15	mml>1+Shadow+SAA

7 Memory Management:

The onboard software stops sending the packets to SSR on encountering a memory full signal. The packets in the onboard memory accumulates. At any instant the difference between wpn and rpn gives the number of packets remaining to be sent to BDH. A maximum of 832 packets can be stored in the onboard memory. The memory management techniques have been designed in a way to reduce the number of packets generated over a period of time and still be able to obtain some information about the detectors. 4 levels of memory have been defined based on the difference between wpn and rpn. In level zero, the normal mode of operation is chosen. If the difference is greater than 300 (level 1) enters reduced mode of operation is entered, the parameters of which are as defined by ground command. If the difference is greater than 500 (level 2), onboard software packetizes the SSM data and header data once in every 100-second. If the difference is greater than 700 (level 3), onboard software packetizes the header data every 100-second. In this level, the SSM data is not packetized. If the difference is greater than 827 (level 4), onboard software stops the data packetisation.

8 Data Identification

The following types of data are obtained as packets from the processing electronics are

1. Detector data
2. Quadrant header data
3. Quadrant SSM data
4. EEPROM data
5. PE header data

The type of data in a particular packet is identified using the data ID. Unique data ID is given for each of the aforementioned data types depending on the mode of operation of the quadrant. Data packetization is done either at a 1s boundary or a 100s boundary. The current mode ID decides the data preparation & packetization at the second boundary and the modes encountered in the last 100sec window defines the pared or not in a hundred second boundary depends on the operating mode of the previous hundred seconds.

<u>One second data:</u>

One second data is identified using the MS bit of Data ID (which is zero for 1s data). It corresponds to detector data from the four detector quadrants. This can result either from a normal mode or a reduced mode of operation. The reduced mode of operation can be entered into in 2 ways: either due to memory unavailability or due to explicit command from ground in that regard. Accordingly, the corresponding reduced mode parameters will be accessed and the reduced mode specified by these parameters will be operational. There are 3 basic reduced modes of operation and combinations of these three are also defined. The exact reduced mode/normal mode is identified using the mode ID.

<u>100s data:</u>

100s data consists of quadrant header packet, SSM data and PE header packet. Quadrant header packet is sent if at any second during the 100s window, a 1s data was not sent. This can happen due to the following conditions:

1. Packet count specified in reduced mode is 0.
2. CZT and Veto HV were Off
3. Shadow region was entered into
4. Memory unavailability

In the header packet, 8 words of FEB header from each second's data will be compiled for the 100 seconds. The mode id for each second is also included along with the header. From this mode id, the reason for 1 sec data not being sent (any of the four reasons mentioned above) can be understood.

SSM data will be sent unless both CZT and Veto HV were off throughout the 100s window. PE header will be sent if all the quadrants were off throughout the 100 seconds.

If a quadrant is OFF, the 5V monitor and CZT and Veto HV monitor locations in LBT are zeroed.

Data ID	Description
0	Q0 detector data
1	Q1 detector data
2	Q2 detector data
3	Q3 detector data
4	Q0 Header data
5	Q1 Header data
6	Q2 Header data
7	Q3 Header data
8	Q0 SSM data
9	Q1 SSM data
10	Q2 SSM data
11	Q3 SSM data
12	Page 0 EEPROM data
13	Page 1 EEPROM data
14	Page 2 EEPROM data
15	Page 3 EEPROM data
16	PE Header data

9 Packetization Format

The HBT data constitutes of individual packets of 1024words.Any data to be sent to the ground from the PE through BDH is packetized into multiple packets. The data sent as HBT packets normally contain detector data , header data, reduced mode data , spectrum data , PE header data or EEPROM data. A group of packets among which a particular set of data is contained constitutes a frame. Multiple sets of such frames are identified by a 'frame number'. Within a frame multiple packets are identified using a 'packet number'. Packet number also facilitates in identifying packet misses and data order. Frame number is 16 bit and packet number is 4 bit and both start from 0.Each packet has a 4 word header. The first packet of the frame (i.e, packet 0) has extra 12 words header along with the 4 word packet header termed as 'frame Header' . The rest of the data in the packet contains the data to be packetized. Packet 0 of the frame can hold 1008 words of data and rest of the packets in the frame can hold 1020 words. Word 3 of header specifies the number of valid words of the packet excluding the packet header. The unused words of the packet are filled with zeros.

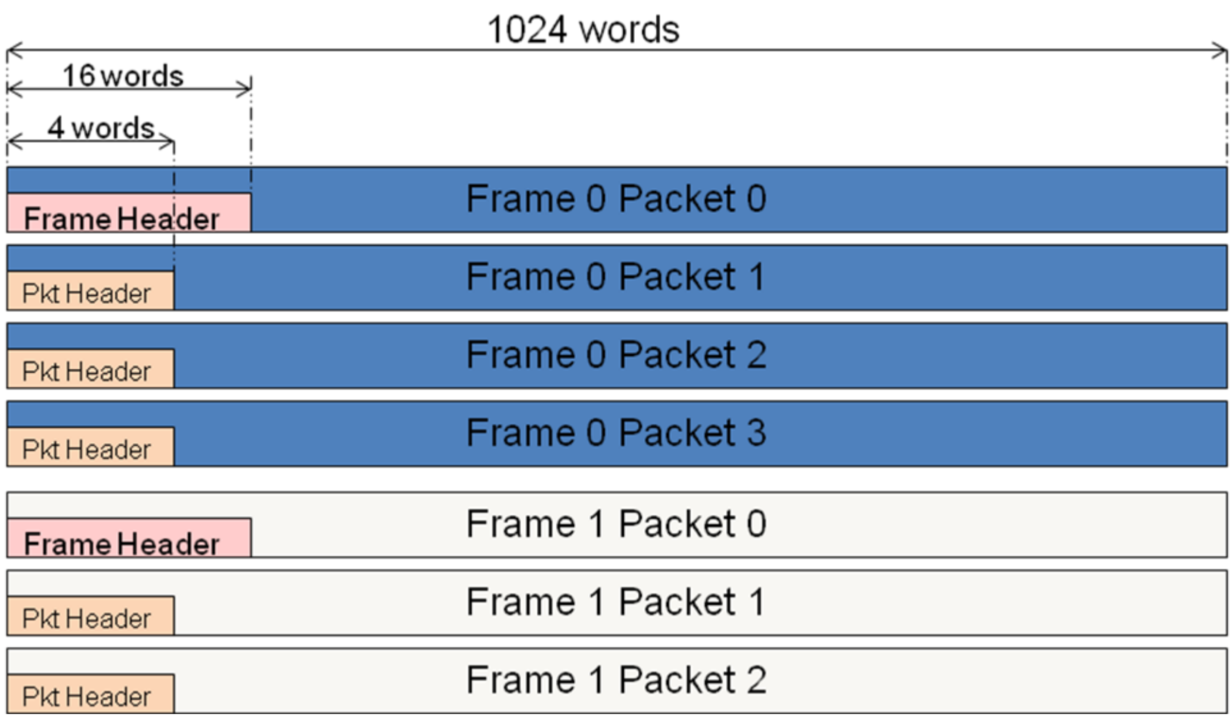
Frame Header

Word	Content	Comment
0	Sync UW	F9A4
1	Sync LW	2BB1
2	Memory Level+ Data ID + Packet number + Mode ID	14:13 Memory level 12:8 Data ID 7:4 Packet number 3:0 Mode ID
3	Number of valid data words in the packet	Range 1 to 1020
4	Frame number	16-Bit
5	Status word	16-Bit status port
6	Write packet number	192 -1023
7	Read packet number	192 - 1023
8	Command UW	Input Port 5
9	Command LW	Input Port 4
10	Second count UW	SCNT UW [31 : 16]
11	Second count LW	SCNT LW [15 : 0]
12	LAXPC time[15:0]	LAXPC time[15:0]
13	LAXPC time [31:16]	LAXPC time [31:16]

Word	Content	Comment
14	Error count + Error flag + LAXPC time[39:32]	15:12- error count 11:8 - error flag 7:0 - LAXPC time [39:32]
15	double words of detector data read (DCNT 0x0080 – 0x1280)	15:14 – Boot page No. 13:0- dcnt

Packet Header :

Word	Content	Comment
0	Sync UW	F9A4
1	Sync LW	2BB1
2	Memory Level+ Data ID + Packet number + Mode ID	14:13 Memory level 12:8 Data ID 7:4 Packet no. 3:0 Mode ID
3	Number of valid data words in the packet	Range 1 to 1020



General packetizing schema

10 Data Formats

10.1 FEB data formats:

FEB data is sent against one second command from PE. In command mode operation 256 words of data will be sent . In event mode of operation, event reports are added so a maximum of 9472 words are sent.

FEB data structure

Word	Description	No. of words
0-23	Header	24
24-255	Veto Spectrum	232
256-9471	CZT event reports	3072 *3

Header: 24 words

Word	Data	Description
0	Status word	
1	HK info	One of the 8 HK channels as specified in table
2	Command	Last received command by the FEB from PE
3	Alpha count	No of Alpha counts registered in last sec
4	Veto Count	No of Alpha counts registered in last sec
5	CZT count < ULD	No of CZT counts less than ULD registered in last sec
6	CZT count ≥ ULD	No of CZT counts great than ULD registered in last sec
7	CZT data read	Response to Last detector read command
8-23	Temperature read	Response of 16 det to temperature measurment

0th word: Status word

Bit	Data	Description
15-12	-	
11	Veto spectrum range	1:Veto spectrum Ranges from 0-231 0:Veto spectrum Ranges from 24-256
10-8	Base address	Base address of the RAM (0-7)
7	Buffer number	Toggles each second
6	Command status	1: Command received last sec , 0: No command
5	Event Read Mode	1: FEB in event mode , 0: FEB in command mode
4	CZT Status	1: Command sent to CZT ,0: Command not sent to CZT
3-0	CZT Number	CZT number to which command was sent

1st word: HK Data

D15	D14 –D12	D11 – D0
0	HK Channel number	ADC output

For each second channel number is incremented and corresponding ADC output will be observed. The description of eight HK channels is given below. One of these channels' parameter is sent to PE every second.

HK Parameters sent to PE

Channel no.	**Description**	**Voltage level**
1	Supply voltage	+5V
2	Thermistor	0V -5V
3	VCCA	2.5V
4	CZT HV	0/5V
5	Veto HV	0/5V
6	DVDD	+ 3.3 ± 0.15 V
7	Veto LLD	0V to 5V

Event Report: 3 words

D47-D32	D31-D20	D19-D16	D15-D8	D7-D1	D0
Time (20us)	CZT energy	Detector ID	Pixel ID	Veto ADC	Alpha

(Maximum number of events that can be stored in memory is 3072).

10.2 LBT data format:

Low Bit Rate telemetry data gives an instant status about the status of the quadrants. 65 bytes of data contain Quadrant related information as well as PE related information.

Quadrant related information :

All these parameters are updated every second after reading the detector data.

Nomenclature	**RMU MUX Address in hex**				**TM Sampling Rate**	**Description**
	Q1	**Q2**	**Q3**	**Q4**		
Mode	00	10	20	30	8 s	Mode of operation + command/event mode
+5V monitor	01	11	21	31	128 s	Voltage at FEB 5V (HK1)
MSB CZT count	02	12	22	32	8 s	MSB of CZT<ULD
Temperature	03	13	23	33	128 s	Value from thermistor (HK2)
LSB CZT count	04	14	24	34	8 s	LSB of CZT<ULD
+2.5V monitor	05	15	25	35	128 s	FEB 2.5V (HK3)

Nomenclature	RMU MUX Address in hex				TM Sampling Rate	Description
	Q1	Q2	Q3	Q4		
Veto HV monitor	06	16	26	36		HV supply to Veto (HK4)
CZT HV monitor	07	17	27	37		HV supply to CZT (HK5)
MSB Veto count	08	18	28	38	8s	MSB of Veto Count
Veto LLD	09	19	29	39	64 s	LLD for Veto events (HK7)
DVDD	0A	1A	2A	3A		DVDD supplied to CZT (HK6)
MSB Alpha count	0B	1B	2B	3B		MSB of Alpha count
LSB Veto count	0F	1F	2F	3F	8s	LSB of Veto count

PE related HK parameters and description:

4 parameters from PE Last received command, 24 bits from the Second count , 40bits of LAXPC time stamp and a SYNC byte are included in the LBT bytes.All these parameters are updated at second boundary.

Nomenclature	RMU MUX Address in hex	TM Sampling Rate
Second Count bits [23:16]	0C	64 s
CMND UW : bits [15:8]	0D	
CMND UW : bits [7:0]	0E	
Second Count bits[15:8]	1C	
Command LW : bits [15:8]	1D	
Command LW : bits [7:0]	1E	
Second Count bits[7:0]	2C	
LAXPC time bits[39:32]	2D	
LAXPC time bits[31:24]	2E	
LAXPC time bits[23:16]	3C	
LAXPC time bits[15:8]	3D	
LAXPC time bits[7:0]	3E	
SYNC word	40	8 s

SYNC Word Description:

Bits [7:5] – Memory level

Bits [4:3] - Software version number

Bits [2:0] – LS 3 bits of error count

10.3 HBT data formats:

Normal mode frame format (Mode ID 0)

Under normal mode of operation all the detector data from the FEB except the 16 words of temperature measurement data are packetized every second. From the CZT<ULD slot of the detector data the number of packets generated for a particular detector in a particular second can be calculated. Number of events is equal to the minimum of 3072 and CZT<ULD.

No. of words from the detector data to be packetized (Nwords)

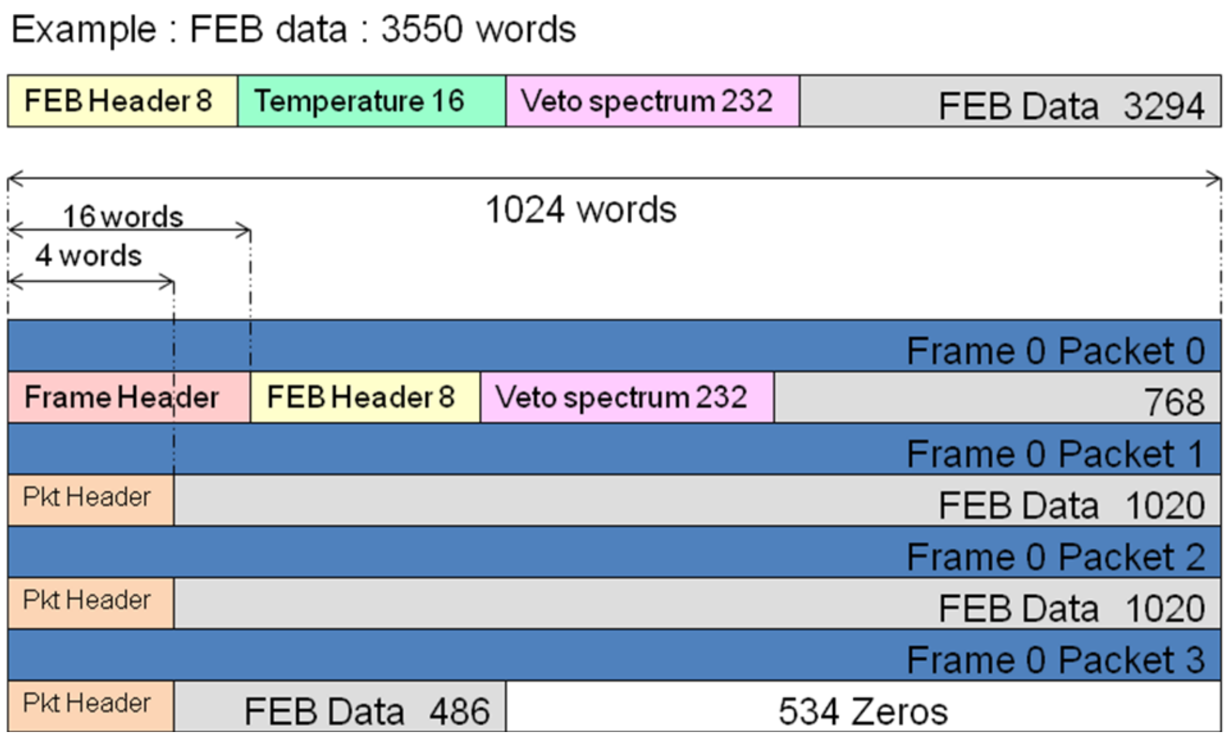
*Nwords= (No. of events * 3)+ 8 words FEB Header + 232 words Veto spectrum*

No. of packets generated from the Nwords (Pnormalpackets)

Pnormalpackets = 1 + Ceil { (Nwords – 1008) / 1020) }

Word	Content	Comment
0-15	Frame header	Frame header
16 – 255	FEB data header + veto spectrum	FEB header(8 words) + veto spectrum(232 words)
256	Time	16 Bit time
257	12 Bit Event energy + 4 bit Detector ID	[15:4] Event Energy [3:0] Detector ID
258	8 bit Pixel ID +4 bit Veto Energy+ 1 bit Alpha	[15:8] Pixel ID [7:1] Veto Energy [0] Alpha
259-1023	Event data same as 257 to 259	

Above shown packet format is for first packet in a frame. If frame contains several packets, then from second packet onwards, words 0 to 3 are packet header and words 4 to 1023 are continuation of event data from previous packet. Word 3 is used to calculate the number of valid words in that packet excluding packet header.



Quadrant Header Frame format (Data ID 4-7)

Under conditions of SAA, shadow , HV OFF there are no events expected from the Detectors every second as the High Voltages are OFF. Also when the memory level is greater than 1, PE onboard memory cannot accommodate event data, only header data is stored so that some information is available for a longer duration of time. In all these cases, the 8 words header of the FEB data of every quadrant is accumulated in the memory every second for duration of 100 sec. At the 100sec boundary one packet per quadrant containing 24 words header of the 100th second FEB data, command history to a max of 64 commands i.e 128 words, 16 PE status words, 12 Quadrant status words ,mode counts and 800 words of accumulated header information is sent as a Quadrant Header packet. Conversely at the 100sec boundary, Quadrant header packet will be sent , if 1sec mode data was skipped any moment in the last 100sec window due to any of the aforementioned conditions.

Word	Content	Comment
0-15	Frame header	Frame header
16-39	24 words FEB header	24 words of current FEB header
40-167	128 words Command history	History of 64 commands received

Word	Content	Comment
168-183	16 words PE status Word	16 PE status words
184-195	12 words Quadrant Status Word	12 Quadrant Status words
196-199	4 words Mode count	Time spent in 1 sec mode, CZT OFF , Veto OFF , SAA time in a 100-second window
200-999	100 * 8 words FEB Header	FEB header of 100 seconds
1000-1023	Fill with zeros	

Reduced mode:

Reduced modes of packetization are implemented only on the FEB data.These are intended to reduce the number of packets generated from a given set of detector data every second as a part of memory management. The complete information from the detector data will not be available in these packets. Reduced mode of packetization is done in 2 cases : when memory level is l and when reduced mode is forced from the ground through command. The same command is used force reduced mode and to set the parameters pertaining to both the conditions.

3 arguments are commanded from ground:

Fixed number of packet: The actual number of packets of a data set sent to the ground is the minimum of fixed number of packets specified and the number of packets required to accommodate the complete data set. Default is 15. This option is considered only if the value is not 15 conversely if this option has to be unchecked the value has to be set back to 15.

Veto spectrum Enable/Disable: This flag specifies the inclusion of 232 words of veto spectrum data from FEB data in the HBT packet. By Default it is enabled. In this packet the events start from 24th word in the first packet.

2 Word event report : This is a flag specifying if the 3word event report is to be reduced to 2word.This is achieved by reducing the time from 16 bits to 9 bits , Event energy from 12bit to 9 bit and Veto energy from 4 bits to 1 bit.

The resultant reduced mode can contain any one of the above parameters implemented individually or a combination of these resulting in 7 reduced modes. 3 types of packets are described below and others will follow similar schema. The modeID table can be referred to the ModeID of each of the combinations. The lower 3 bits of the Mode ID indicates the presence of reduced mode. Bit 0:Veto spectrum disable , Bit 1:2Word event , Bit 2: Fixed number of packets. Other combinations are correspondingly generated.

Veto Spectrum Disable (Mode ID 1)

Word	Content	Comment
0-15	Frame Header	Frame Header
16-23	FEB data header	8 words FEB data header
24	Time	16 Bit time
25	8 bit Event energy + 4 bit Detector ID	Event Energy : Bits [15:4] Detector ID: Bits [3:0]
26	8 bit Pixel ID +7 bit Veto Energy+ 1 bit Alpha	Pixel ID : Bits [15:8] Veto Energy: Bits [7:1] Alpha: Bit 0
27-1023	Event data same as 24 to 26	

2 Word Event (Mode ID 2)

Word	Content	Comment
0 – 15	Frame Header	Frame Header
16-259	FEB data header + veto spectrum	8 words FEB data header + 232 words veto spectrum
260	9-Bit time + 7 MS Bits of event energy	2 Word Event Report
261	Next 2 MS Bits of event energy +8-Bit pixel ID + 1 Bit Veto + 1 Bit Alpha+ 4 Bit Detector ID	
262-1023	Event data same as 260 to 261	

Veto Spectrum Disable + 2 Word Event (Mode ID 3)

Word	Content	Comment
0 – 15	Frame Header	Frame Header
16-23	FEB data header	8 bit FEB header
24	9-Bit time + 7 MS Bits of event energy	2 Word Event Report
25	Next 2 MS Bits of event energy +8-Bit pixel + 1-Bit Veto +1-Bit Alpha+ 4 Bit Detector ID	
26-1023	Event data same as 24 to 25	

SSM mode packet format (Data ID 8-11) :

3 types of spectrums are prepared every second from the detector event data. Spectrum is accumulated for 100sec. The veto spectrum (256 words) is updated from the 232 word Veto spectrum from the detector data depending on a bit in FEB header which specifies if the spectrum corresponds to first 232 or last 232 words. CZT spectrum (512 words) is updated with event energy of all events. CZT with veto spectrum is updated for events which are coincident with veto and has a non zero veto ADC value associated with them. CZT with alpha and without veto is updated for those events which have no veto associated with them but has the alpha bit set.

The 4096 word energy spectrum is reduced to 512 word in the following way:

- Channels less than 950 are accumulated at 950 and channels above 2047 are accumulated at 2047
- In other channels LS 2 bits are ignored or energy is right shifted by 2 without carry.

Along with the spectrum 24 word header, Command history, 16 PE status Words, 12 Quadrant Status Words, Mode count is also included.

Packet number	Word	Content	Comment
0	0 – 15	Frame Header	Frame Header
	16-39	24 words FEB header	FEB header
	40-1023	Integrated spectra as specified by the Table below	
1	0-3	Packet Header	Packet Header
	4-1023	Integrated spectra as specified by the Table below	

Integrated spectrums in SSM mode for every 100-seconds

Packet number	Word	Content
0	40-167	Command history
	168-183	16 PE status Words
	184-195	12 Quadrant Status Words
	196-199	Mode count
	200-455	Veto spectrum
	456-967	CZT spectrum
	968-1023	CZT spectrum with veto
1	4-459	CZT spectrum with veto
	460-971	CZT spectrum with alpha and without veto
	972-1023	Fill With Zeros

PE header mode Frame Format:

PE Header mode is generated only when all the quadrants are OFF. This packet specifies the general working status and various parameters. It is generated once in 100sec.

Word	Content	Comment
0 – 15	Frame Header	Frame Header
16 -39	24 Zeros	
40-167	128 words Command history	History of 64

Word	Content	Comment
		commands
168-183	16 PE status Words	
184-199	Q0 : 12 Quadrant Status Words + 4 words Mode count	Quadrant 0
200-215	Q1 : 12 Quadrant Status Words + 4 words Mode count	Quadrant 1
216-231	Q2 : 12 Quadrant Status Words + 4 words Mode count	Quadrant 2
232-247	Q3 : 12 Quadrant Status Words + 4 words Mode count	Quadrant 3
248-1023	Fill with zeros	

11 Memory Organization in Buffer

Memory capacity of RAM is 2MB (512k x 32). It is divided into 16 pages of 64K each. Two pages i.e. 128k x 16 are allocated for detector data. Thirteen pages i.e. 832k x 16 are allocated for HBT data. LBT data is stored in 256 memory locations of page 0 i.e. 256 x 32.

RAM Organization

Description	**Memory Allocated**	**Address**	**Remarks**
PAGE 0			
Program	7k x 32	0x0000-0x1BFF	
Stack	0.5k x 32	0x1C00-0x1DFF	
Variables	0.5k x 32	0x1E00-0x1FFF	
Detector Initialization commands	20 x 16	0x8000-0x8013	
Detector temperature measurement commands	64 x 16	0x8040-0x807F	
24 words dummy	24x16	0x80E8-0x80FF	Filled with zero
Command history	128 x 16	0x8100-0x8180	64 32-bit commands
PE status words	16 x 16	0x8181-0x818f	6 PE status words
Quadrant status words 8 SWs each quadrant	8 x 16 8 x 16 8 x 16 8 x 16	0x8190 – 0x819B 0x81A0 – 0x81AB 0x81B0 – x81BB 0x81C0 – 0x81CB	Quadrant 0 Quadrant 1 Quadrant 2 Quadrant 3
Time count	4x16 4x16 4x16 4x16	0x819C – 0x819F 0x81AC – 0x81AF 0x81BC – x81BF 0x81CC – 0x81CF	Both HV on, CZT HV off, veto HV off, both HV off status of all 4 quadrants
Detector command Buffer	512 x 16	0x8200 – 83FF	512 commands
Quadrant map	512 x 16	0x8400 – 0x85FF	Quadrant mapping
Expt. status variable buffer	25 x 16	0x8600-0x8618	variables pushed into memory for reloading during watchdog reset
SSM,Header Data preparation buffer			
LBT	512 x 16	0xFE00-0xFFFE	Alternate locations
PAGE 1			
Quadrant 0 Buffer 0	16k	0x0000-0x3FFF	0-16k

Quadrant 1 Buffer 0	16k	0x4000-0x7FFF	16k-32k
Quadrant 2 Buffer 0	16k	0x8000-0xBFFF	32k-48k
Quadrant 3 Buffer 0	16k	0xc000-0xFFFF	48k-64k
Quadrant 0 Buffer 1	16k	0x0000-0x3FFF	0-16k
Quadrant 1 Buffer 1	16k	0x4000-0x7FFF	16k-32k
Quadrant 2 Buffer 1	16k	0x8000-0x9FFF	32k-48k
Quadrant 3 Buffer 1	16k	0xC000-0xFFFF	48k-64k
PAGE 3 to 15			
HBT	832k x 16	0x0000-0xFFFF	192k-1024k

Table 2: EEPROM Organization

EEPROM Page Number	Address	Address set Command for start address of each page
0	0x00000 – 07FFF	0xC00E 0000
1	0x08000 - 0FFFF	0xC00E 8000
2	0x10000 – 17FFF	0xC00F 0000
3	0x18000 – 1FFFF	0xC00F 8000

		Address				
	Memory Allocated	**Quadrant 0**	**Quadrant 1**	**Quadrant 2**	**Quadrant 3**	**Remarks**
SSM data	24 x 16	0x9000-0x9017	0xa000-0xa017	0xb000-0xb017	0xc000-0xc017	Header
	128 x 16	0x9018-0x9097	0xa018-0xa097	0xb018-0xb097	0xc018-0xc097	Command History
	16 x 16	0X9098-0X90a7	0Xa098-0Xa0a7	0Xb098-0Xb0a7	0Xc098-0Xc0a7	PE SW
	16 x 16	0X90a8-0X90b7	0Xa0a8-0Xa0b7	0Xb0a8-0Xb0b7	0Xc0a8-0Xc0b7	Quad SW+ mode count
	256 x 16	0X90b8-0X91b7	0Xa0b8-0Xa1b7	0Xb0b8-0Xb1b7	0Xc0b8-0Xc1b7	Veto Spectrum
	512 x 16	0x91b8-0x93b7	0xa1b8-0xa3b7	0xb1b8-0xb3b7	0xc1b8-0xc3b7	CZT spectrum
	512 x 16	0x93b8 – 0x95b7	0xa3b8 – 0xa5b7	0xb3b8 – 0xb5b7	0xc3b8 – 0xc5b7	CZT with veto
	512 x 16	0x95b8-0x97b7	0xa5b8-0xa7b7	0xb5b8-0xb7b7	0xc5b8-0xc7b7	CZT with alpha
Header data	24 x 16	0xd000-0xd017	0xd400-0xd417	0xd800-0xd817	0xdc00-0xdc17	24 word Header
	128 x 16	0xd018-0xd097	0xd418-0xd497	0xd818-0xd897	0xdc18-0xdc97	Command History
	16 x 16	0Xd098-0Xd0a7	0Xd498-0Xd4a7	0Xd898-0Xd8a7	0Xdc98-0Xdca7	PE SW
	16 x 16	0Xd0a8-0Xd0b7	0Xd4a8-0Xd4b7	0Xd8a8-0Xd8b7	0Xdca8-0Xdcb7	Quad SW+ mode count
	800x16	0Xd0b8-0Xd3d7	0Xd4b8-0Xd7d7	0Xd8b8-0Xdbd7	0Xdcb8-0Xdfd7	Header of 100-second

Status Words

Quadrant Status Word [12 words]

Commanded status / default status of each of the below parameters.

SW	Bits	Description
SW0	Bits[15:0]	Event mode On/OFF
	Bits [7:0]	-
SW1	Bit [15:8]	Event mode read enable disable of det 15:8
	Bits [7:0]	Event mode read enable disable of det 7:0
SW2	Bit [15:8]	Veto LLD
	Bits [7:0]	RAM Select
SW3	Bit [15:8]	CZT HV
	Bits [7:0]	Veto HV
SW4	Bit [15:8]	CZT Parity
	Bits [7:0]	-
SW5	Bit [15:8]	CZT ULD
	Bits [7:0]	CZT Reset
SW6	Bit [15:8]	-
	Bits [7:0]	Veto spectrum range
SW7	Bit [15:8]	-
	Bits [7:0]	-
SW8	Bit [15:8]	T1
	Bits [7:0]	
SW9	Bit [15:8]	T3
	Bits [7:0]	T2
SW10	Bit [15:8]	T5
	Bits [7:0]	T4
SW11	Bit [15:8]	T7
	Bits [7:0]	T6

PE Status Word [16 words]

Commanded status and actual status of each of the below parameters.

PE SW	Bits	Description
0	Bits[15:0]	Command count
1	Bits[15:14]	2 bits SAA selection Logic
	Bit[13]	Quadrant command enable/disable
	Bits[12:8]	5 bits EEPROM unlock & time
	Bits[7:4]	4 bits 2W event report status of all quadrants at MF
	Bits[3:0]	4 bits Veto spectrum disable status at MF
2	Bits[15:12]	Veto HV commanded status
	Bits[11:8]	Veto HV actual status
	Bits[7:4]	CZT HV commanded status
	Bits[3:0]	CZT HV actual status
3	Bits[7:4]	Q0 packet count in RM
	Bits[3:0]	Q0 packet count in MF
4	Bits[7:4]	Q1 packet count in RM
	Bits[3:0]	Q1 packet count in MF
5	Bits[7:4]	Q2 packet count in RM
	Bits[3:0]	Q2 packet count in MF
6	Bits[7:4]	Q3 packet count in RM
	Bits[3:0]	Q3 packet count in MF
7	Bits[11:8]	Detector i/f Error status of 100-second window
	Bits[7:0]	QON status
8	Bits[15:0]	Version No.
9 to 15		Spare

Mode Count (4 Words)

Time in last 100 sec window spent in each of the below cases.

Word	Bits	Description
0	[6:0]	Both HV On / 1 sec mode
1	[6:0]	CZT HV Off
2	[6:0]	Veto HV Off
3	[6:0]	Both HV Off / SAA mode

12 Details of modes of operation

MID	MML	DID	Prep Int	Pack Int	Remarks
0	0	0-3	1 sec	1 sec	Default Normal mode format of packetization at 1sec boundary
		4-7	1 sec	100 sec	In the last 100sec window between (1-99 sec) if any of Mode ID 4-7 (with Fixed num of pkt count=0) or 9-15 was encountered for at least 1sec
		8-11	1 sec	100 sec	Default type of packetization at 100 sec boundary
1-7	0,1	0-3	1 sec	1 sec	Reduced mode of packetisation commanded or Memory full from SSR
		4-7	1 sec	100 sec	In the last 100sec window between (1-99 sec) if any of Mode ID 4-7 (with Fixed num of pkt count=0) or 9-15 was encountered for at least 1sec.
		8-11	1 sec	100 sec	If non-SAA state existed in last 100sec window at least for 1 sec
9-11	0,1	4-7	1 sec	100 sec	Default Quadrant header type of packetization
		8-11	1 sec	100 sec	If non-SAA state existed in last 100sec window at least for 1 sec
12-15	2	4-7	1 sec	100 sec	Default Quadrant header type of packetization
		8-11	1 sec	100 sec	If non-SAA state existed in last 100sec window at least for 1 sec
	3	4-7	1 sec	100 sec	Default header type of packetization
	4	No preparation or Packetisation			
PE Header and EEPROM packets : always Mode ID - 0					
MID:0 PE header	0-3	16	100sec	100sec	When all quadrants are OFF
	4	No preparation or Packetisation			
MID:0 EEPROM	0,1	12-15	Prepared & packetized in the 1sec boundary of receipt of request		
	2,3,4	No preparation or Packetisation			

MID : Mode ID ; DID: Data ID ;MML:Memory Level ;Prep Int : Preparation Interval ; Pack Int: Packetization Interval