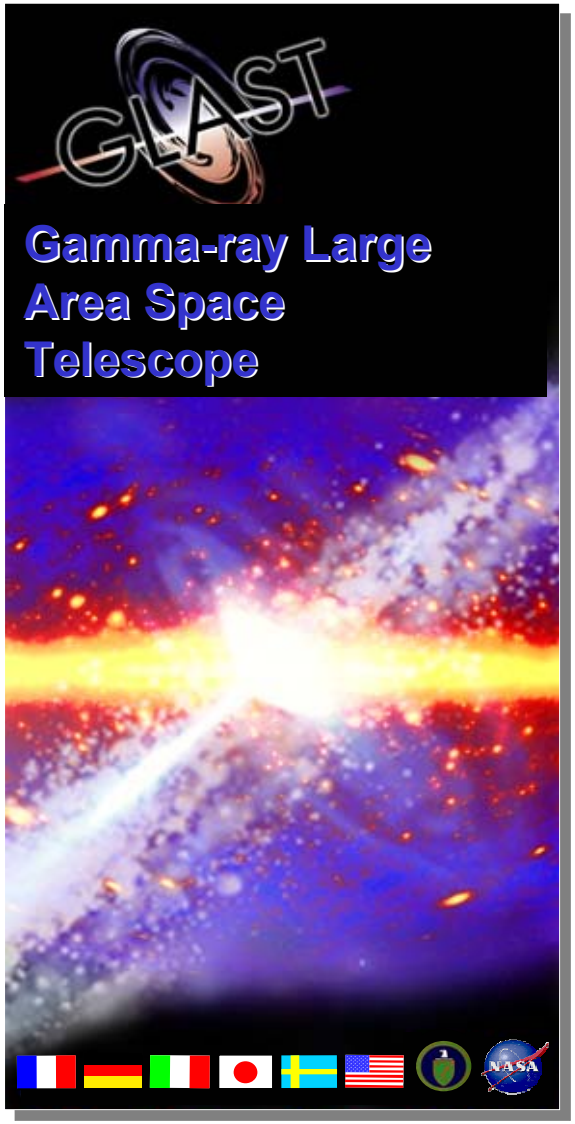


GLAST Large Area Telescope:

Electronics, Data Acquisition & Instrument Flight Software

Flight Software I

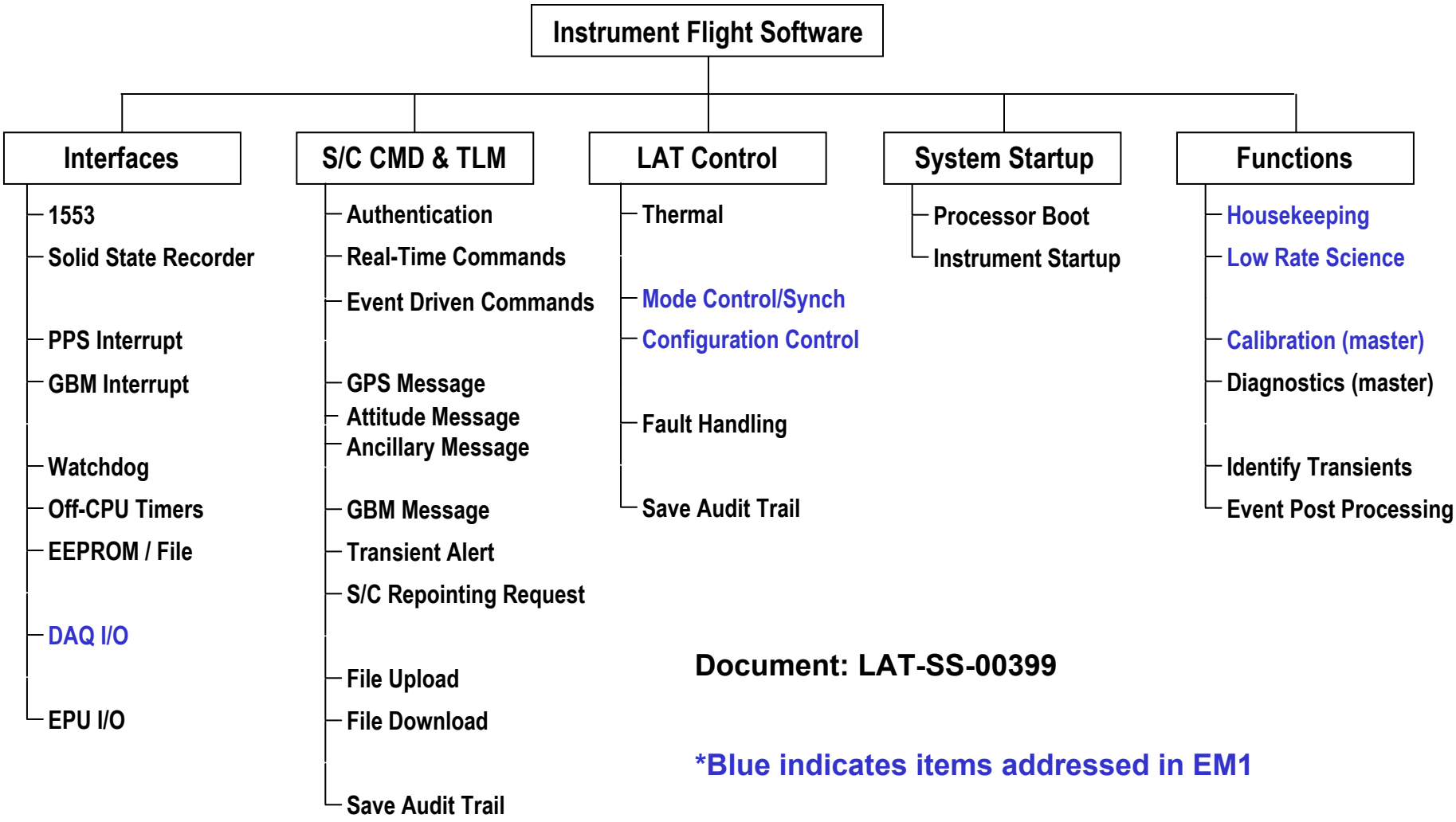
A.P.Waite
Stanford Linear Accelerator Center
Engineering Physicist

apw@slac.stanford.edu
(650) 926-2075

Outline

- Key Functional Requirements
- FSW Interfaces
  - Logical
  - Physical
- Communications
  - 1553
  - LCB
- Architecture
- File Management
- LAT Command and Telemetry
- Housekeeping

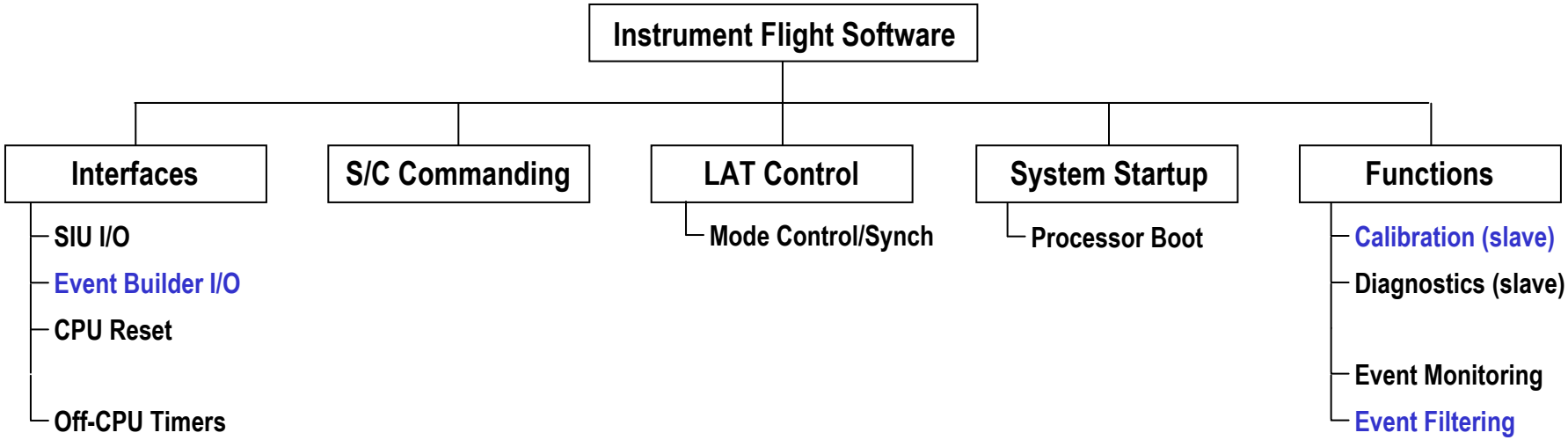
Derived Functional Requirements (SIU)



Document: LAT-SS-00399

*Blue indicates items addressed in EM1

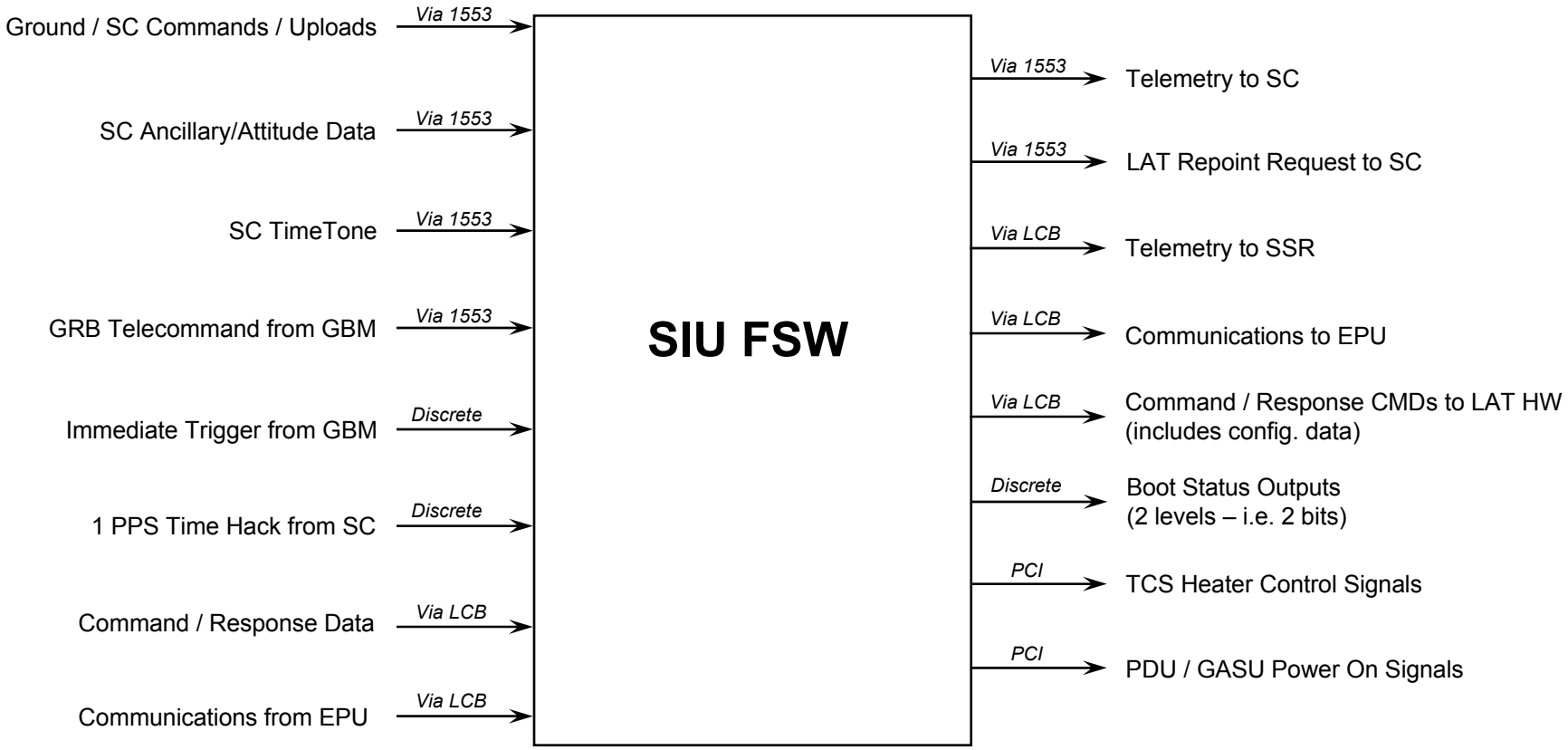
Derived Functional Requirements (EPU)



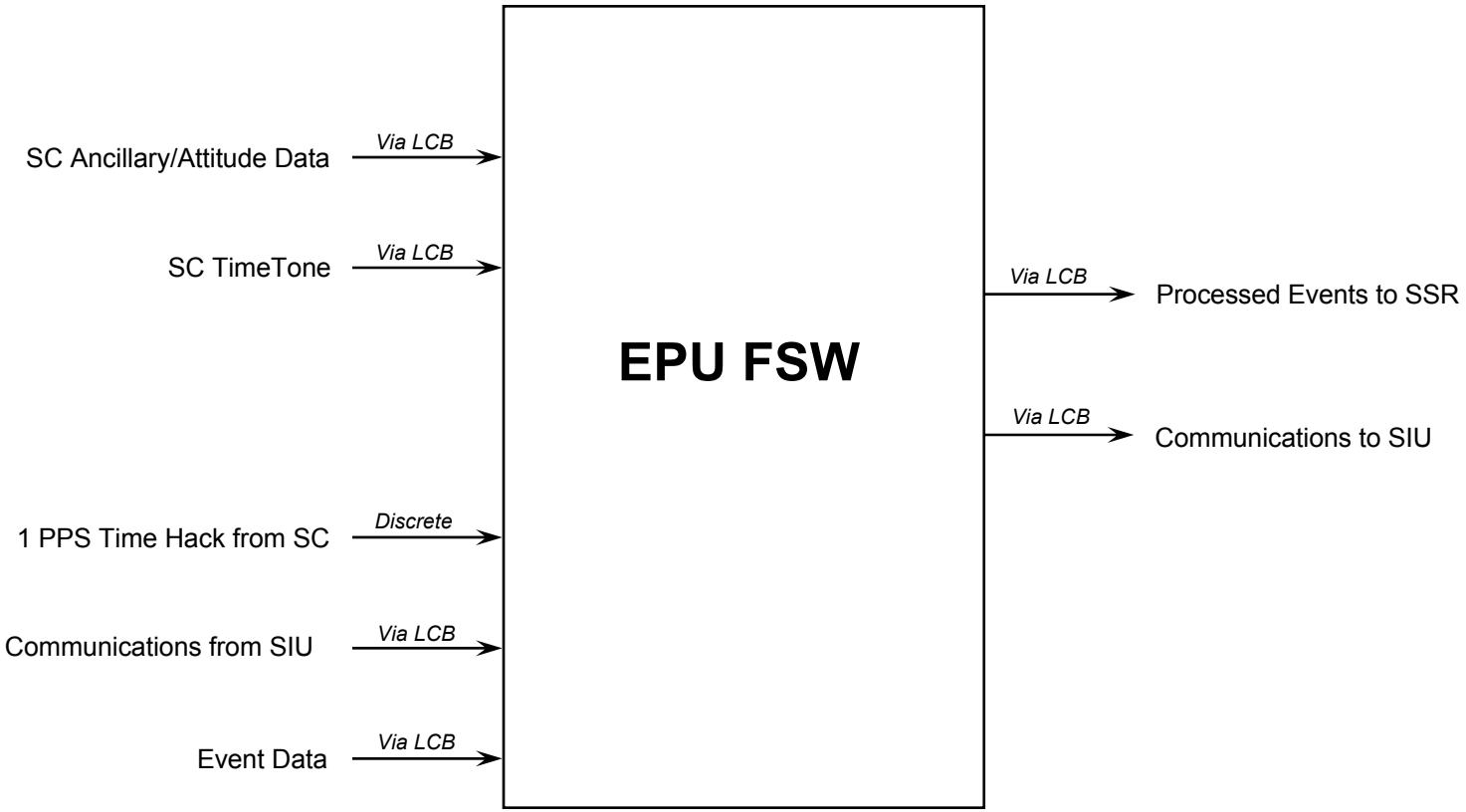
Document: LAT-SS-00399

***Blue indicates items addressed in EM1**

FSW External Interface Summary – SIU



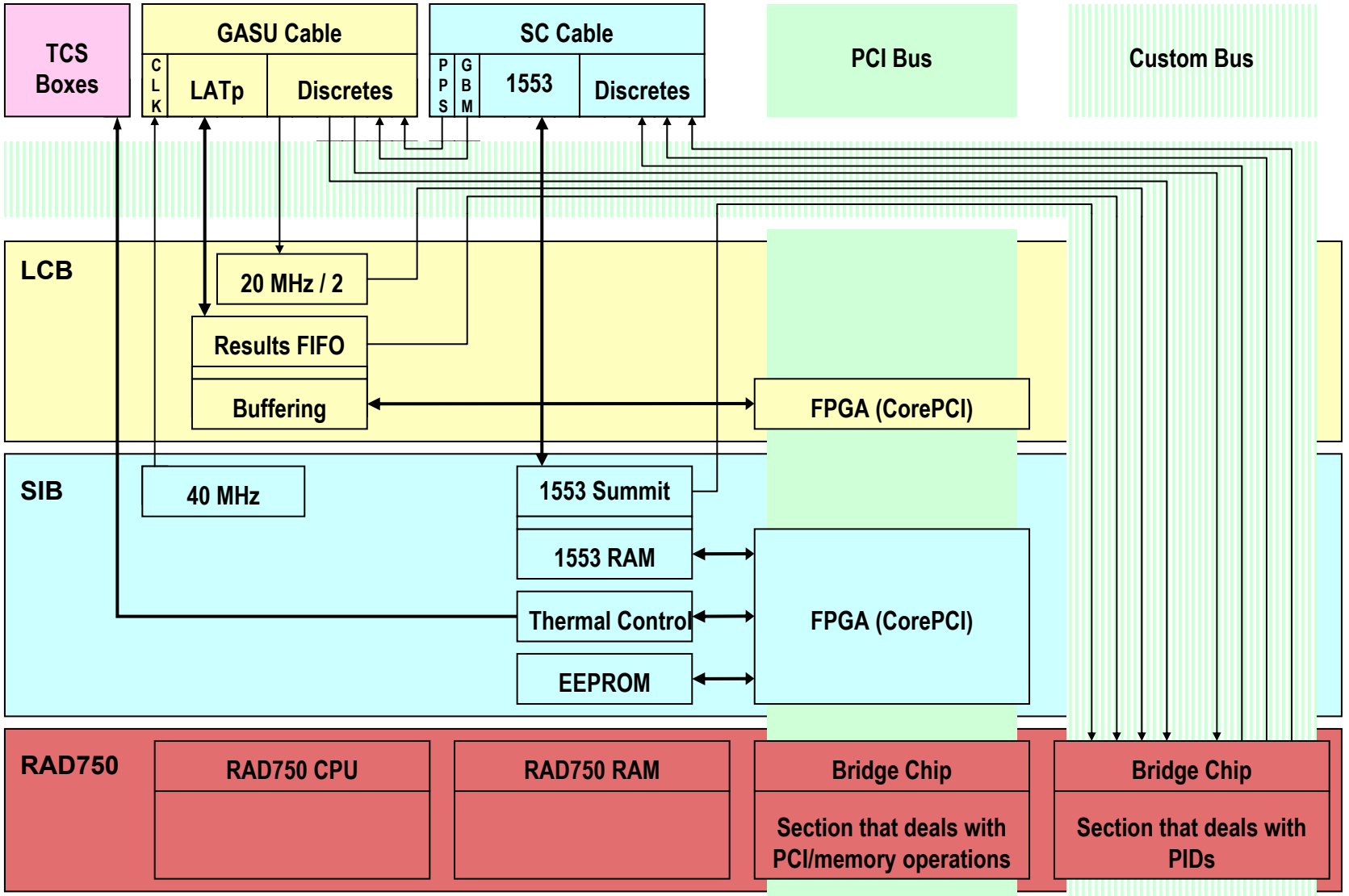
FSW External Interface Summary – EPU



RAD750 External Interfaces

- In flight configuration the RAD750 by itself has two interfaces
  - PCI interface
    - PCI standard bus, 32 bits wide, 33 MHz
  - Programmable Input/Output Discretes
    - Provided as a feature of the RAD750
    - Programmability includes
      - Input or output
        - » Inputs can be configured to deliver interrupts
      - Time/timer functions
        - » Driven by internal or *external* clocks
- The RAD750 board is mounted in a crate with a custom backplane

RAD750 Interfaces: Backplane, PCI and PIDs



RAD750 PID Assignment

#	Input	SIU	EPU	Input/Output
23-25	SC Inputs 0-2	Y		Input
21-22	GBM Interrupt Primary/Redundant	Y		Input
17	LCB PCI Interrupt	Y	Y	Input
16	SIB PCI Interrupt	Y		Input
15	Select Me	Y		Output
14	Clock Enable	Y		Output
11-13	External Clock – Primary	Y	Y	Input
8-10	External Clock – Redundant	Y	Y	Input
7	SC Primary/Redundant Selection	Y		Output
5-6	SC Outputs 0-1	Y		Output
2	LCB Interrupt – Alternate	Y	Y	Input
1	SIB Interrupt – Alternate	Y		Input

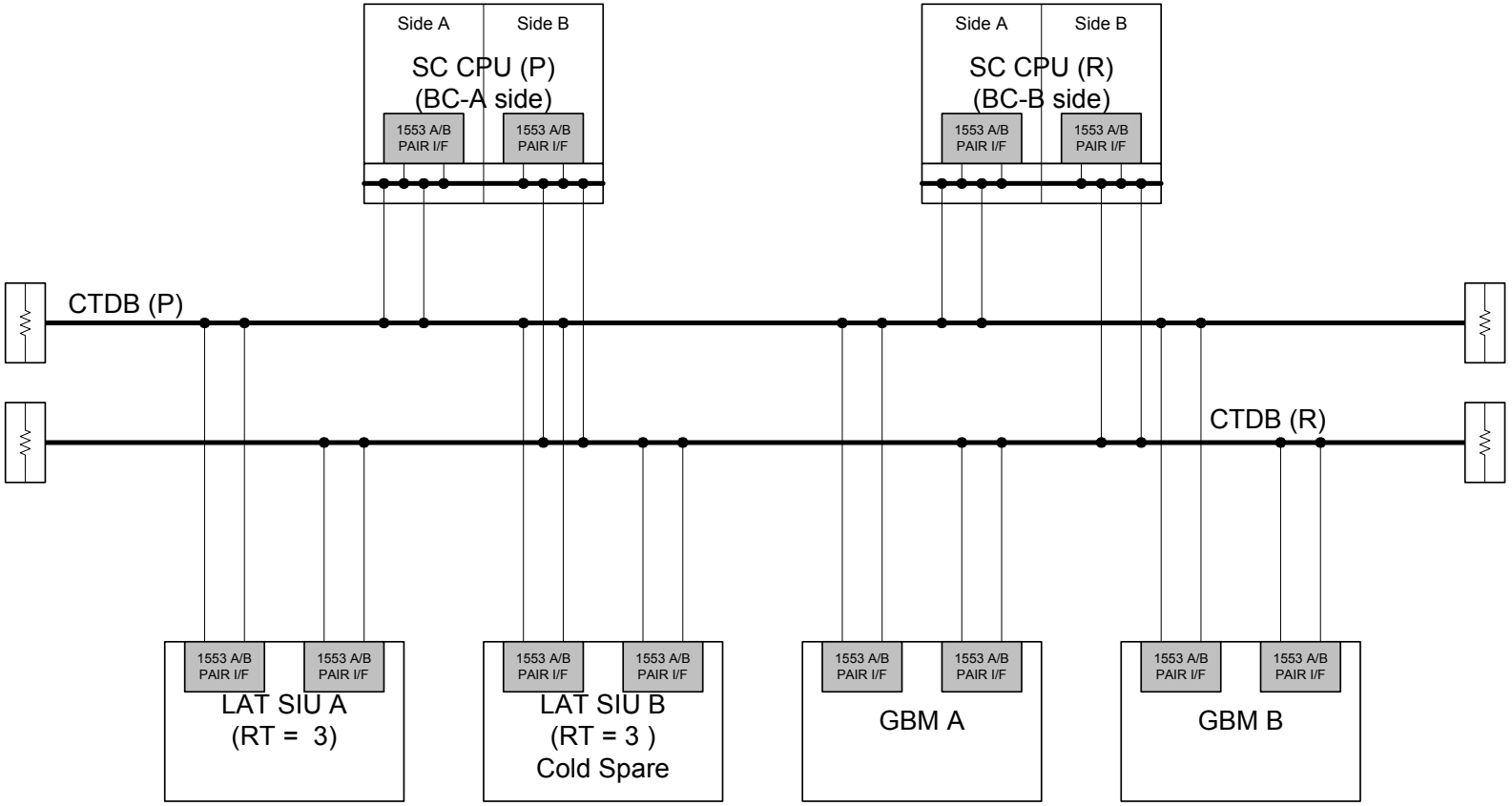
RAD750 Signal Definitions

- SC Inputs
  - 3 general purpose levels from the SC
- Clock Enable
  - Enables the 40 MHz clock to the GASU
- Select Me
  - Contingency
- Clocks
  - 3 Sets, 2 External, 1 Internal
    - Clock, driven by a 10 MHz version of the LAT clock
    - Snapshot, driven by the 1 PPS
    - Clear, driven by a reset signal
  - Purpose
    - 2 External clocks provide the CPUs with a counter synchronized with the system counters
    - 1 Internal clock is used in systems without access to 1 PPS GPS input (test stand)
- SC Primary / Redundant Selection
  - Selects Primary/Redundant SC Inputs/Outputs set
- SC Outputs
  - 2 Lines to provide primary boot status, *before* 1553 is operational

1553 Interface

- MIL_STD_1553B (1553) bus is primary interface for exchanging information between LAT and SC
  - Commands from SC
  - Telemetry to SC
  - Commands to SC (limited to SC Repoint Request)
- SC will act as bus controller (BC) node
- Each SIU can act as remote terminal (RT) node
- Bus protocol and schedule under control of SC
  - Spectrum Astro 1553 Bus Protocol Interface Control Document
- All traffic will consist of CCSDS packets

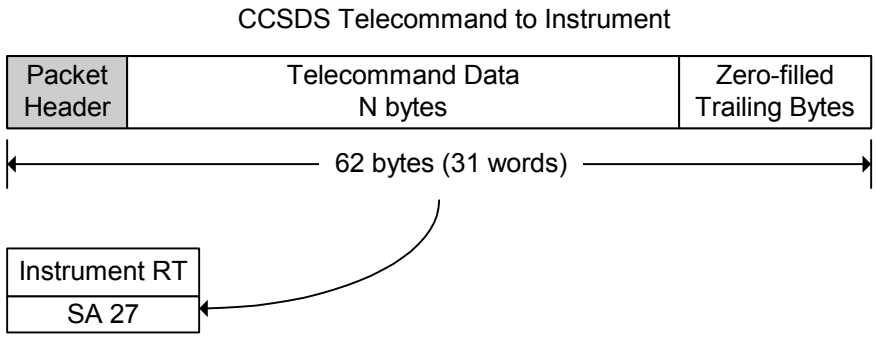
1553 Architecture

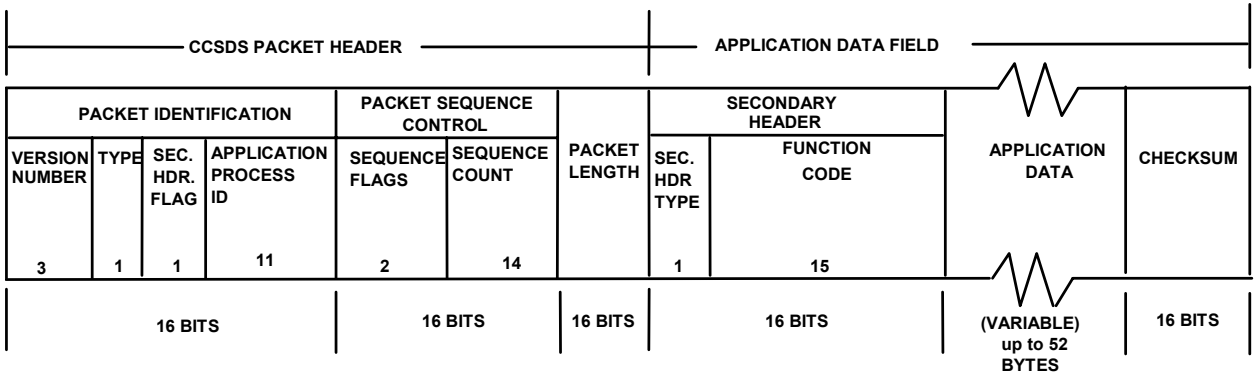


SIU 1553 Subaddresses

Subaddress	Transfer Direction	Transfer Rate	Interface	Description
Command Receive (CmdRx)	BC → RT	3.5 – 10 kbps (3.5 kbps always for SC GPS, time and NAV messages)	Asynchronous	Telecommand input • Ground commands • Ground uploads • SC real-time cmds • SC stored cmds • SC GPS, time, NAV msgs • GBM alert messages
Command Transmit (CmdTx)	RT → BC	0 – 2.5 kbps	Asynchronous	Telecommand output • SC repoint request
Telemetry (Telem)	RT → BC	0 – 30.7 kbps	Asynchronous / Synchronous	Variable-length tlm packets • Real-time housekeeping • Real-time diagnostics • Alerts
Data Wraparound (Wrap)	N/A	N/A	N/A	SC test of RT basic functionality

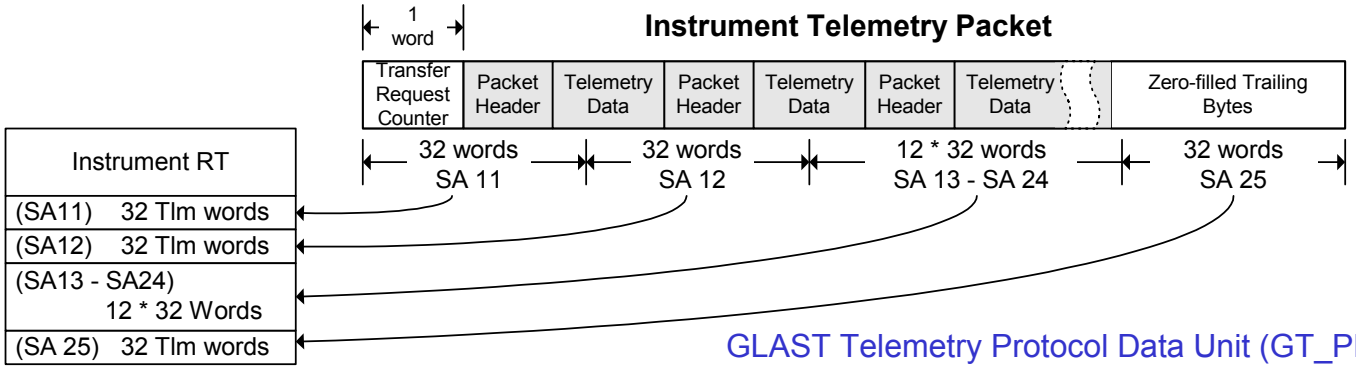
1553 Telecommand Packet Structure





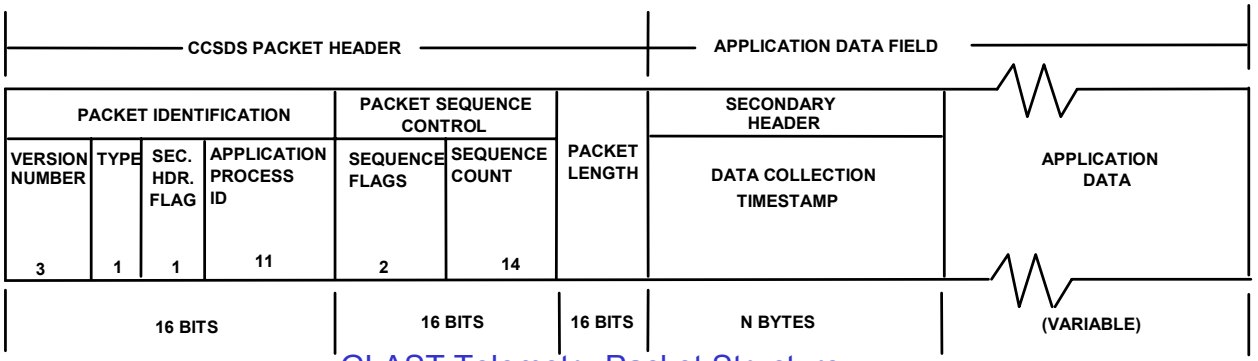
Additional detail in Spectrum Astro 1553 Bus Protocol Interface Control Document

1553 Telemetry Protocol Data Unit Structure



GLAST Telemetry Protocol Data Unit (GT_PDU) Structure

Telemetry transfers use 960 byte data transfer block



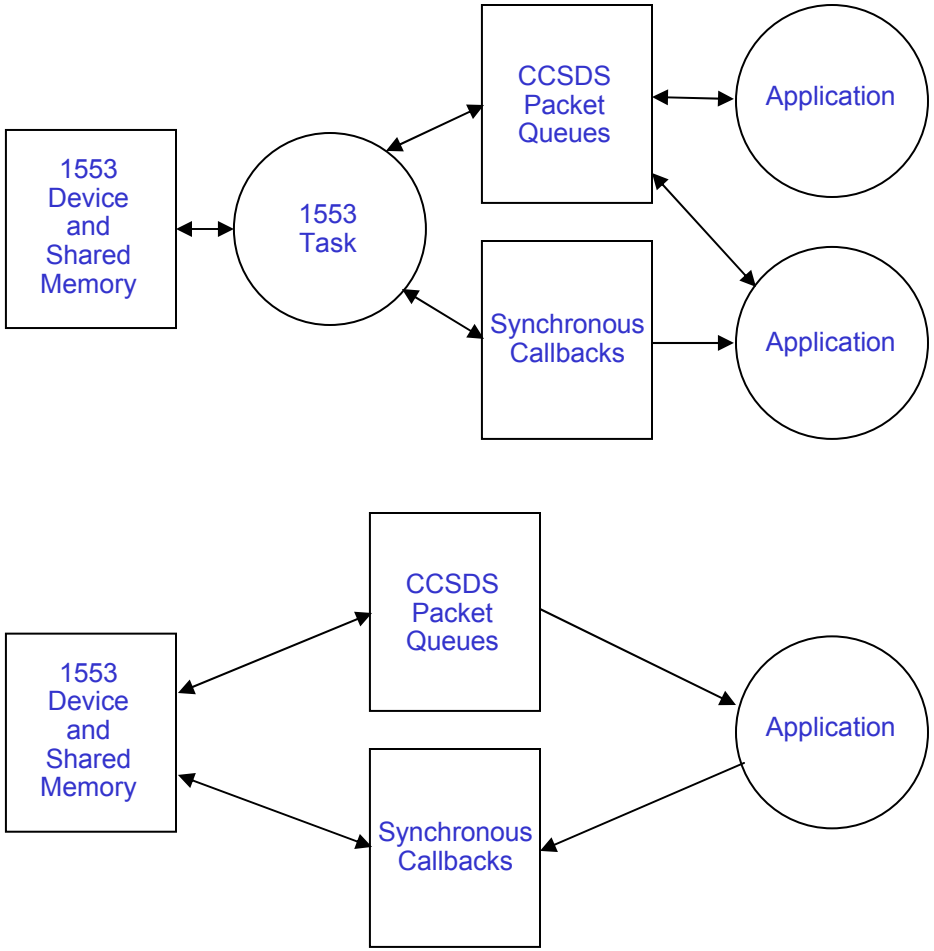
GLAST Telemetry Packet Structure

Telemetry transfers use 960 byte data transfer block

Additional detail in Spectrum Astro 1553 Bus Protocol Interface Control Document

SIU 1553 Drivers

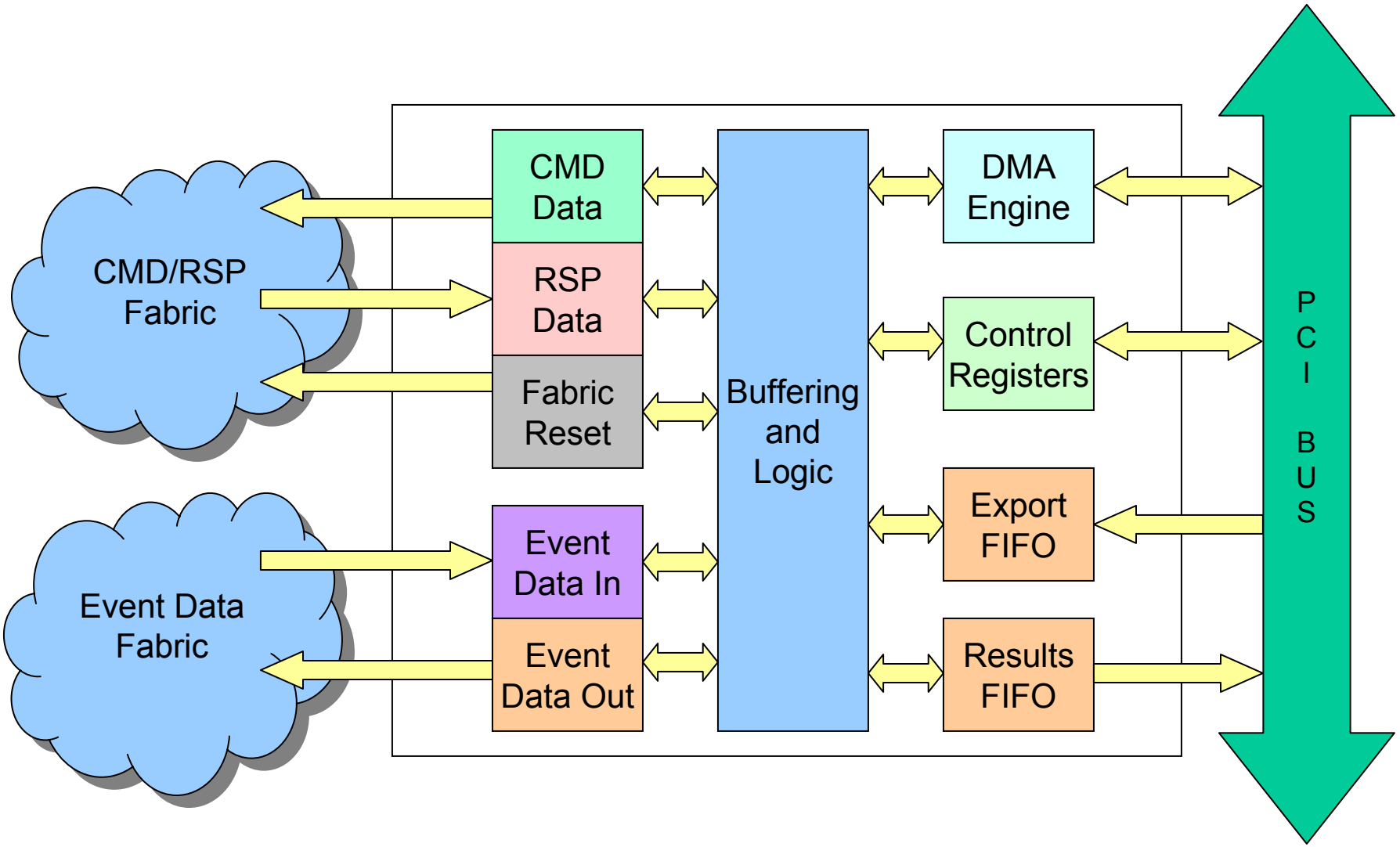
- Interrupt Mode Drivers
  - Intended for use after RTOS has booted and its services are available
  - Provide a service task that responds to controller device interrupts
- Polled Mode Drivers
  - Intended for use before RTOS has booted and is providing
    - Interrupt handlers
    - Multitasking
    - Advanced memory management
  - Less flexible for general use
- Status
  - Design is mature
  - Code already exists



LCB Interface

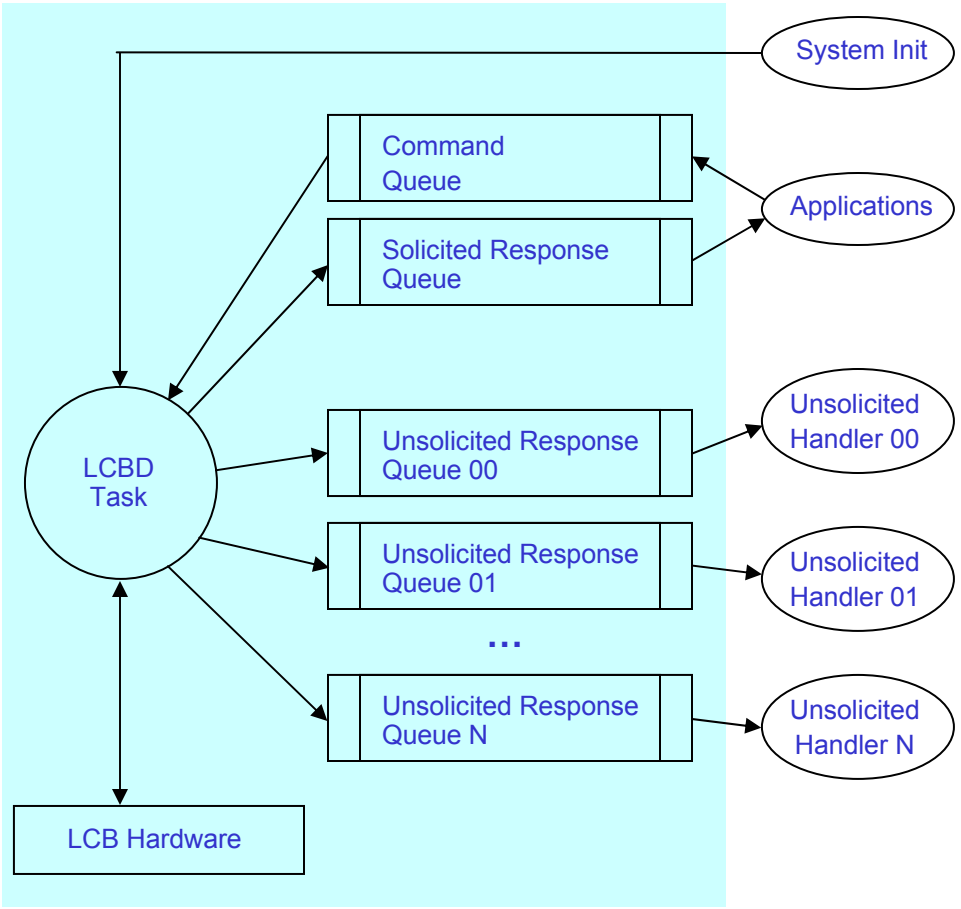
- Communication within LAT provided by LAT Communications Board (LCB)
- Built in two form factors
  - PMC mezzanine card (used for EM1/EM2 with mv2304 SBCs)
  - cPCI module (used for EM2/Flight with mcp750/rad750 SBCs)
- LCB communicates with nodes on the command and event fabrics
  - Instrument to CPU (asynchronous, event fabric)
  - CPU to CPU (asynchronous, event fabric)
  - CPU to SSR (asynchronous, event fabric)
  - CPU $\leftrightarrow$ instrument (synchronous, command/response fabric)
- LATp is packet protocol for all traffic through this interface

LCB Architecture



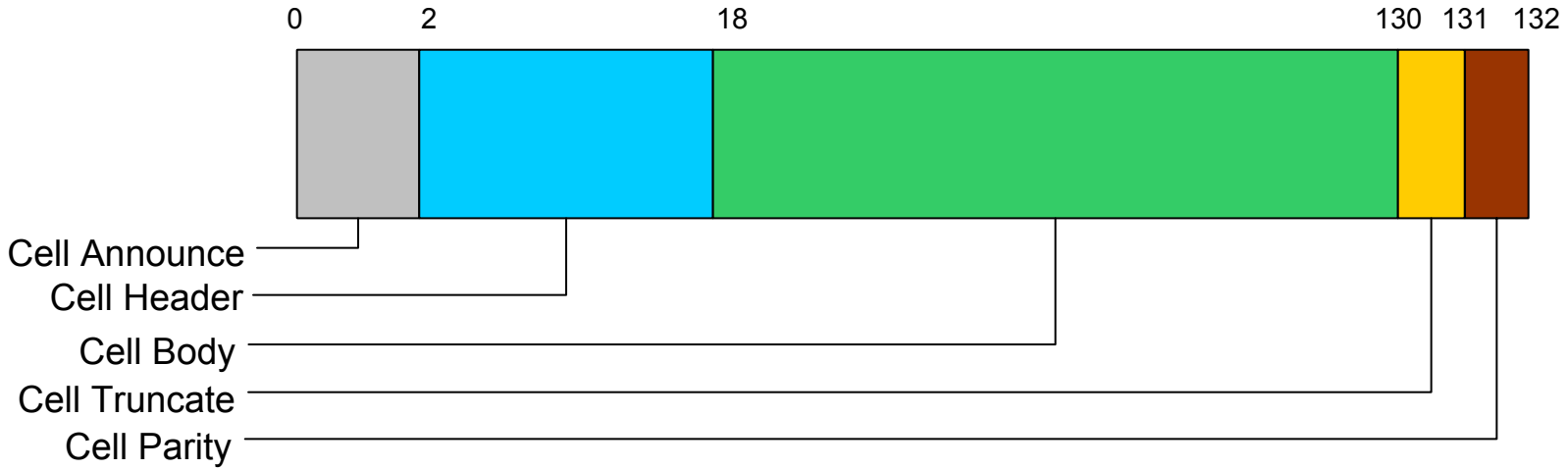
LCB Drivers

- Document: LAT-TD-01380
- Hardware Interface Driver
  - Supports low-level services of the LCB
    - Access to LCB PCI registers
    - Initialization and configuration routines
    - PCI utility/convenience routines
  - Intended as private interface used by LIO to support high-level public interface
- Interrupt Mode Driver
  - Public, stable interface to multiple users
  - All user applications communicate via LIO interface
- Polled Mode Driver
  - Designed
- Status
  - Code has "seen" the LCB
  - Design less mature than 1553



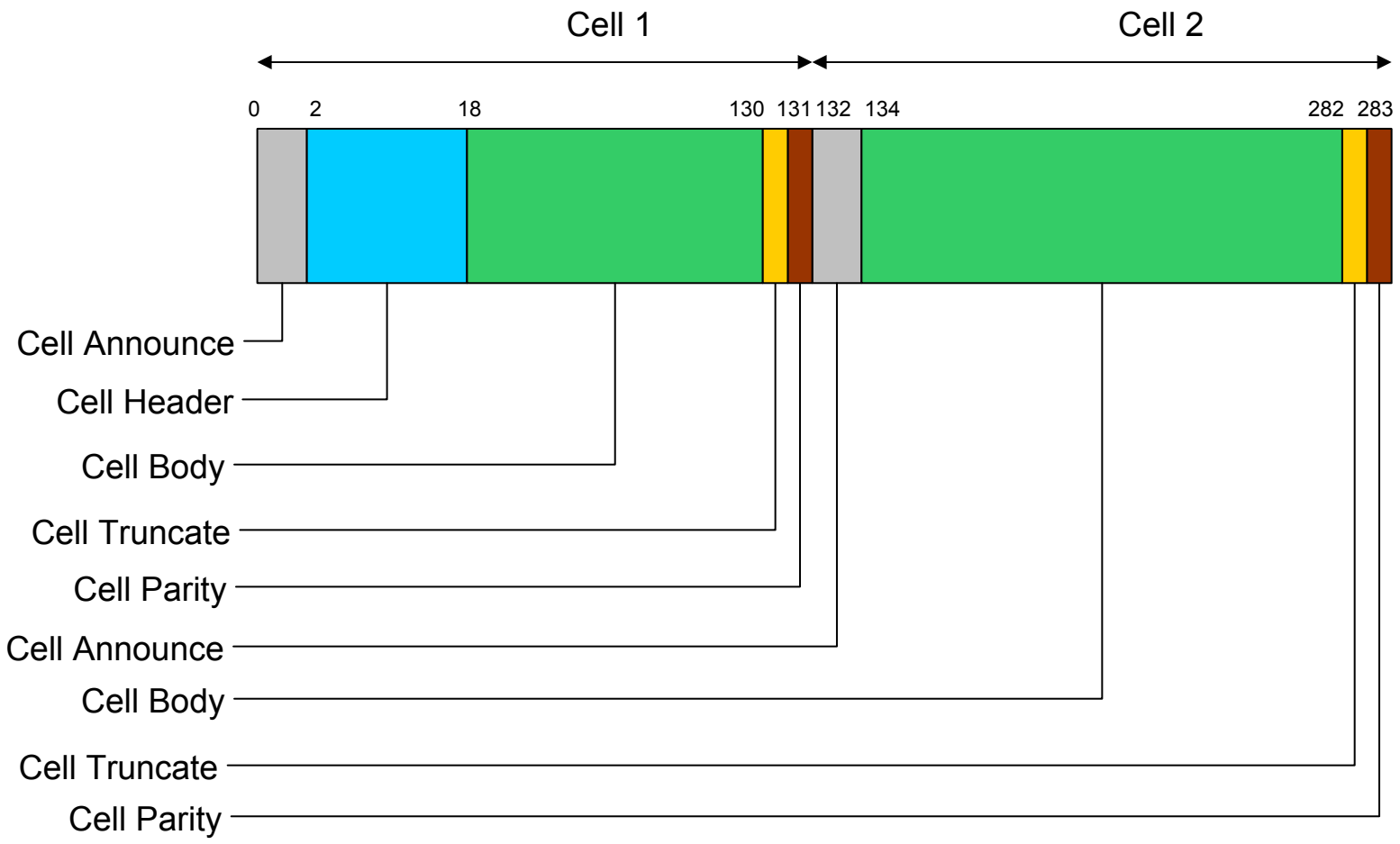
LAT Protocol (LATp) Overview

- Document: LAT-TD-00606
- LATp packet consists of one or more 128-bit LATp cells
  - First cell in sequence contains 16-bit LATp header
  - Each cell is preceded by a 2-bit cell announce sequence
  - Each cell is trailed by a truncate bit and parity bit
- LATp packet formats
  - For hardware configuration, packet formats are specified in programming ICDs
  - For CPU-to-CPU and CPU-to-SSR communications, LATp packets are built up into CCSDS source packets

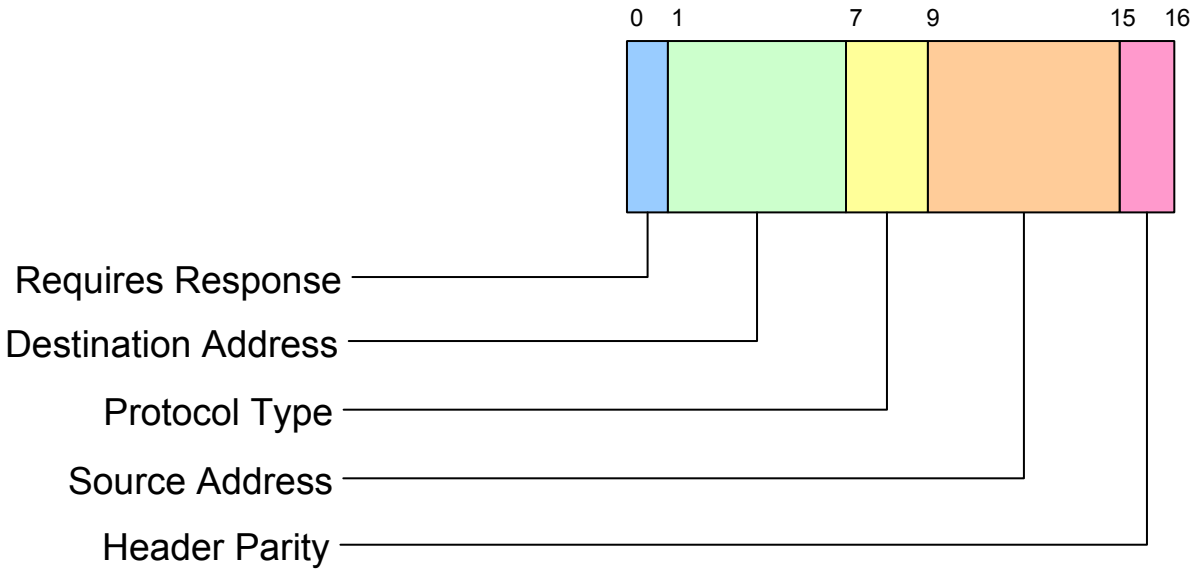


- LATp status
  - Already developed and in use for hardware testing at 16 sites world-wide (SLAC, NRL, GSFC and Italy)

LATp Two Cell Packet Example



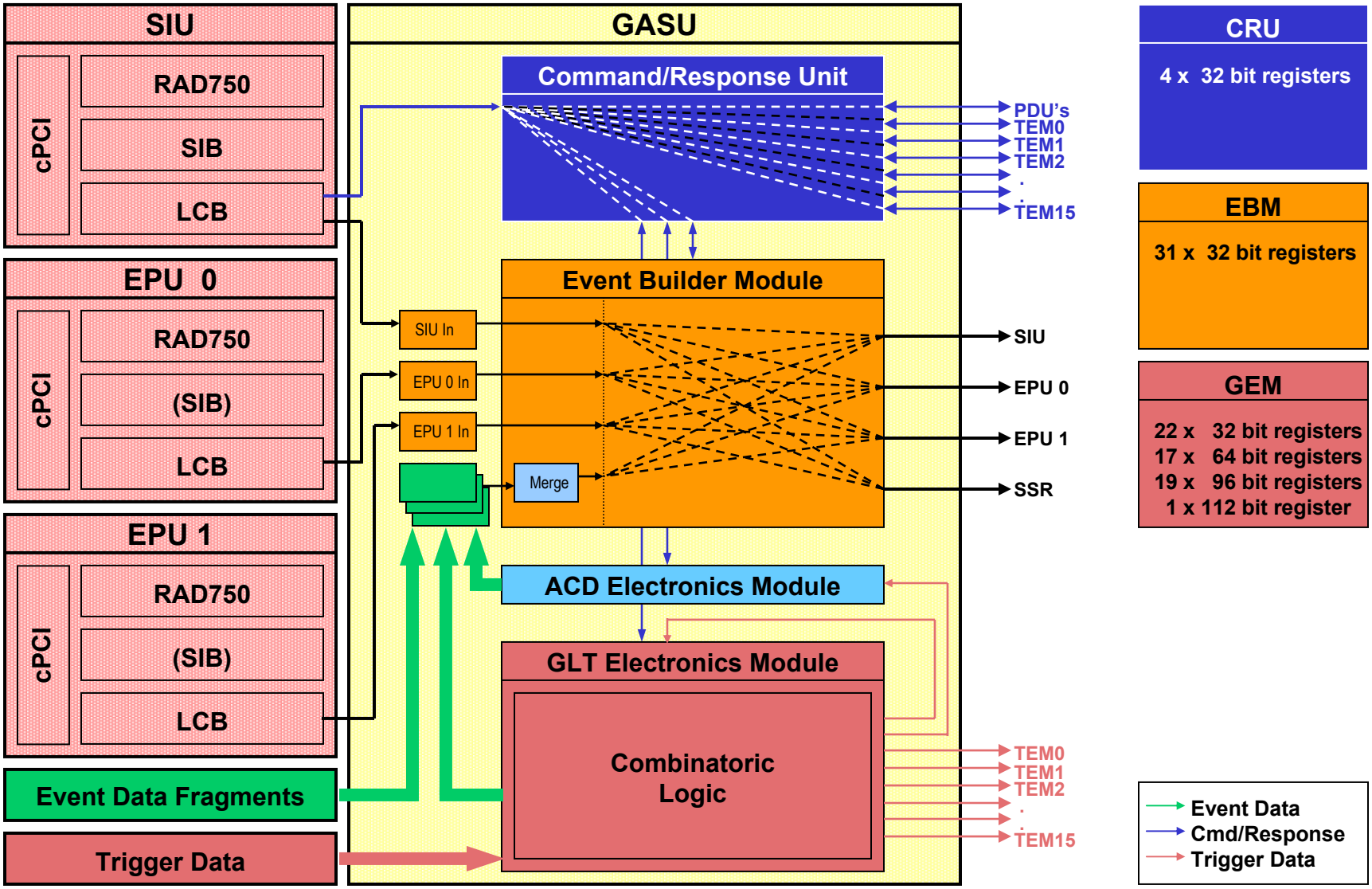
LATp Cell Header



FSW Architecture

- LAT FSW architecture strongly coupled to LAT hardware design
- All LAT-side CPU communications go via the LCB
  - SIU to EPU via GASU (EBM)
  - SIU to PDU for internal power control via GASU (CRU)
    - Initial PDU and GASU power on via separate SIB mechanism
  - SIU to TEMs for instrument configuration via GASU (CRU)
  - SIU to AEM, GEM for instrument configuration via GASU (CRU)
  - Event data to EPU for processing via GASU (EBM)
  - All data to SSR from SIU or EPU via GASU (EBM)

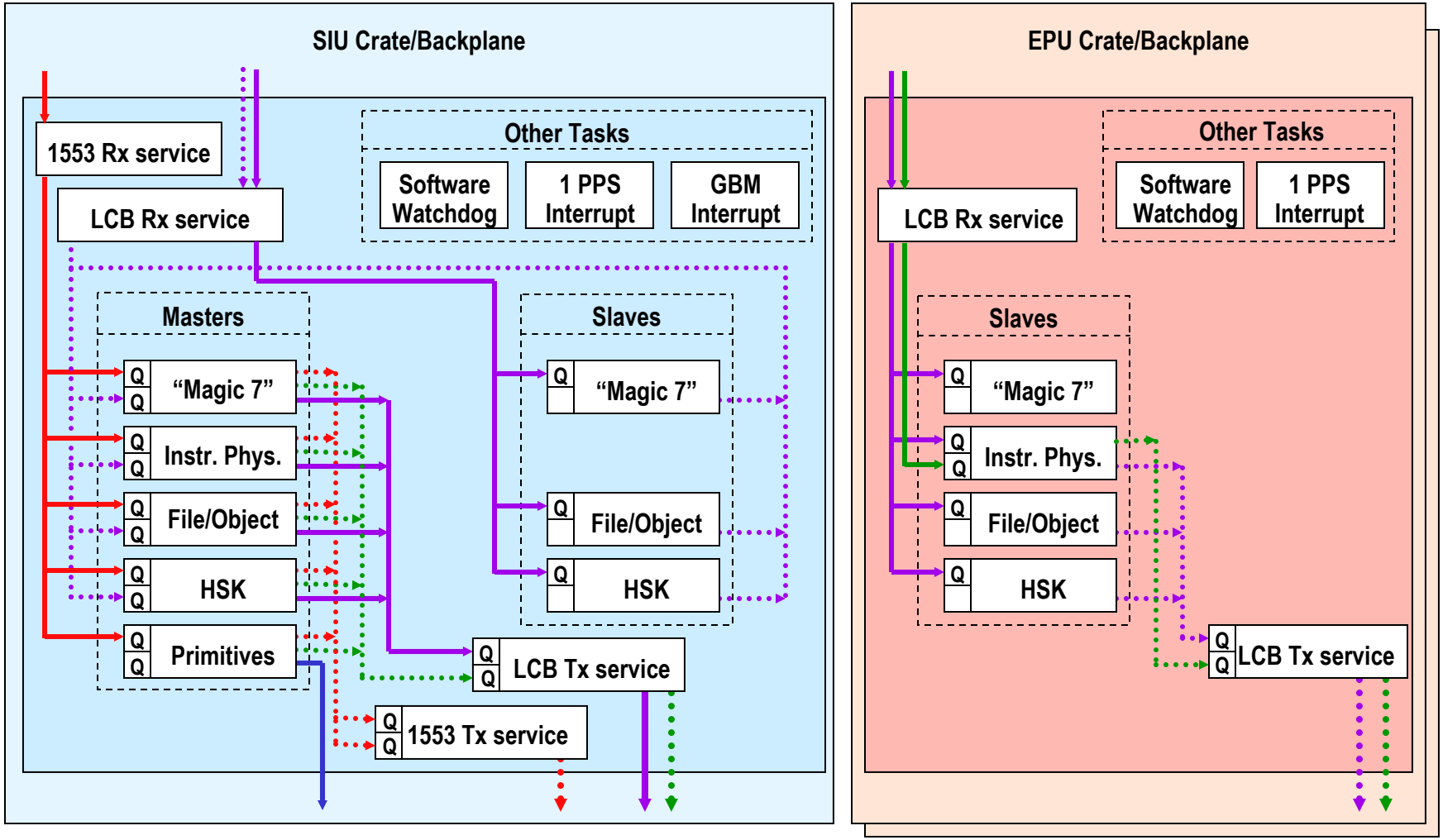
GASU Role in FSW Communications Architecture



FSW Framework

- Fundamental construct for LAT FSW is Master/Slave tasks
  - Master running in SIU
  - Slaves running in SIU or in EPUs or in both
  - Communications between master and its slaves is full-duplex
- Slave tasks may have multiple inputs
  - E.g. a slave task receiving instrument data as well as messages from its master task
  - Slave will have two input queues with priority given to messages from the master task
- Master tasks may also have multiple inputs
  - Needed to achieve connectivity back to the spacecraft
  - Master task will also have two input queues, one from the slave(s) and one from the spacecraft 1553 dispatch, with priority given to the 1553 messages
- Structure of masters and slaves can be replicated as often as necessary to accomplish all the functions required of FSW

FSW Architecture with Internal Framework



Description of Masters

- "Magic 7" deals with dispatching the 7 "magic" messages per second from the spacecraft
  - 5 attitude
  - 1 time-tone
  - 1 ancillary (containing orbit information as well as status info)
- File master deals with all file upload/copy/delete/… processing
- Housekeeping master deals with accumulating and examining housekeeping information
  - Requests info from SIU, EPUs, GASU, hardware
  - Provides monitoring and alarming
  - Outputs telemetry
- Instrument Physics master deals with all instrument data related processing
- Immediate (or primitive) master deals with the very primitive LAT configuration command set

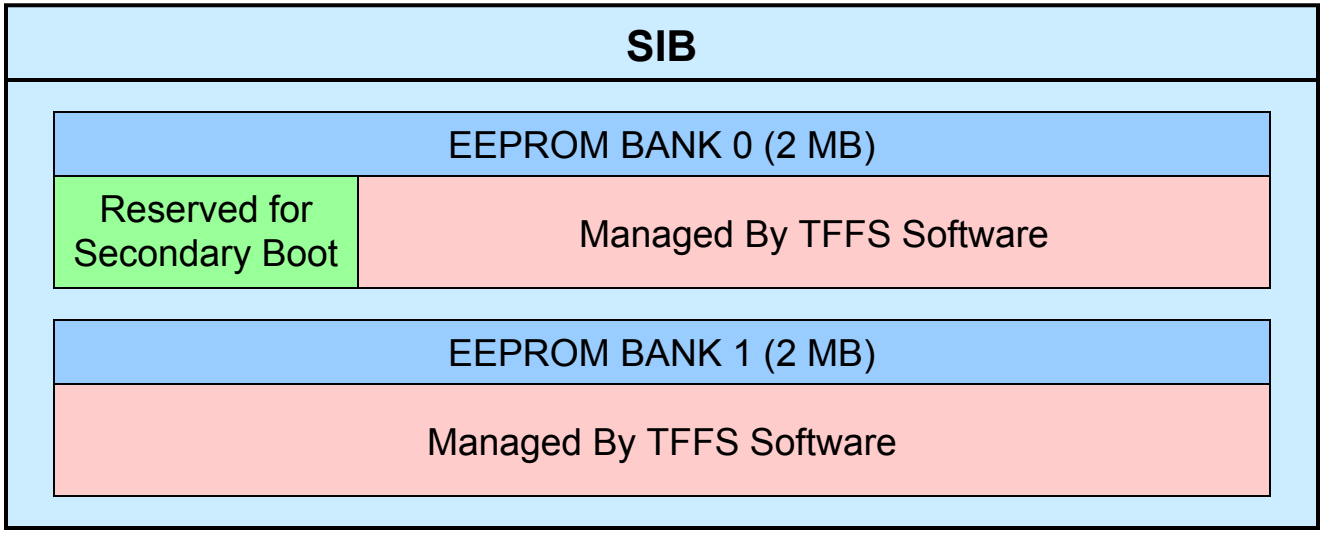
Framework Implementation

- Implemented as a framework so that replication is trivial
- Frameworks then acquire their identities by plugging in routines
  - Plugging in functionality can be a one-time configuration step at system start for static tasks
    - "Magic 7" functional code
    - File master functional code
    - Immediate/primitive master functional code
  - Can also be dynamic at run time
    - Instrument Physics master
      - Physics acquisition code during normal operations
      - Charge injection calibration code
      - Other diagnostics during engineering mode
    - Housekeeping master
      - May collect different kinds of information during various modes (normal observing, calibration, diagnostics, engineering, etc.)

On-Board File System

- LAT will use an on-board file system for storage
  - Configuration files
  - Startup & command scripts
  - Object modules
- File system is managed by TFFS (commercial product)
  - TFFS compensates for the fact that EEPROM is not infinitely writeable
    - Spreads the writes as evenly as possible
    - Manages damaged memory using bad blocking techniques
    - Preserves logical continuity even if the file is not physically contiguous
  - A 4 MB EEPROM with 1000 writes supports 4 GB lifetime
    - During a 5 year mission, can write ~2 MB/day
    - Example of configuration file sizes: TKR mask bits @ 2 bits per strip
      - Stored “dumb”: ~222 kByte
      - Stored “smart” (OR and XOR the bits then gzip): ~20 kByte
      - Update frequency estimated at less than once a week
- LAT Usage of the File System
  - Supports both EEPROM and RAM based file systems
    - Allows testing in RAM before commitment to EEPROM
  - Limits file specifications to 32-bits with sub-directory depth of 1
    - Limitation driven by the size restrictions of telecommand packets

EEPROM Layout



Layout In EEPROM Bank 0		
Address	**Use**	**Comment**
0x00000000	RTOS executable image (compressed)	An *absolutely* linked image
0x00060000	RTOS auxiliary module 0 (SSB0)	Second stage boot executable
0x00070000	RTOS auxiliary module 1 (SSB1)	Second stage boot script
0x00080000	Start of region managed by TFFS	Object & Configuration Files
0x00200000	End	

LAT Command and Telemetry

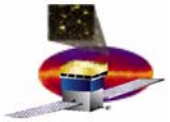
- SIU receives 62-byte CCSDS telecommand packets via 1553 bus
- LAT executes all commands received immediately
  - Complex activities contained in files
    - Configurations
    - Command lists
  - Executed sequentially
  - No scripting
- SC may perform multi-step command procedures by executing sequences of time-tagged commands
- File uploads may be performed in real-time during commanding contacts
- Commands to initiate execution of activities / configurations in files will be stored as time-tagged commands on SC

LAT Telecommands (1)

- Document: Telecommand and Telemetry Formats (Draft)
- Limited number of commands defined to date
  - Boot
  - Commands required to support EM1
  - "Magic 7" SC messages

Boot Telecommands

APID	Function Code	Description
0x640	0	Boot Start. Removes the primary boot code from the initial timeout and allows further operational telecommands or file uploads for the primary boot code to take place.
	1	Boot Reset. Forces a reset of the primary boot code into a known restart state.
	2	Boot Memory Dump Start. Start a dump of memory into the HKP telemetry by the primary boot code.
	3	Boot Memory Dump Cancel. Cancels a primary boot code memory dump that is in progress.
	4	Boot Error Dump. Dump the value of a queued error work by the primary boot code.
	5	Boot RTOS Execute. Begins execution of an RTOS image and the second stage boot process.



LAT Telecommands (2)

File Telecommands

APID	Function Code	Description
0x641	0	File Upload Start. Announces the beginning of a new upload and provides total size and packet count.
	1	File Upload Cancel. Cancels an outstanding upload set.
	2	File Upload Commit. Writes the upload data to the final storage destination.
	3	File Upload Data. Actual file upload data packet string.
	4	File Dump. Dump the contents of a file into telemetry packets.
	5	File Delete. Remove a file from on board storage.
	6	File Copy. Copies the contents of one file into another.
	7	File Directory Dump. Dump a listing of a directory into a series of telemetry packets.
	8	File Object Link. Loads the contents of an ELF object file into memory.

Memory Telecommands

APID	Function Code	Description
0x642	0	Memory Dump. Dump the contents of a range of memory into a series of telemetry packets.
	1	Memory Symbol Lookup. Dump the value of a symbol table symbol into a telemetry packet.
	2	Memory Pool Status. Dump the status of a memory pool into a telemetry packet.

LAT Telecommands (3)

Task Telecommands

APID	Function Code	Description
0x643	0	No Operation. Just sends back a telemetry packet reply.
	1	Reboot. Reboot the processor.
	2	Task Create. Spawns a new task.
	3	Task Delete. Deletes a task.
	4	Task Status. Dump the status of tasks into a series of telemetry packets.

Spacecraft Telecommands

APID	Function Code	Description
0x701	1	SC Attitude (SIATTITUDE). Contains latest SC attitude information.
	2	SC Ancillary (SIANCILLARY). Contains latest SC position and mode.
	3	SC Time (SITIMETONE). Contains synchronization time information for GPS PPS.

LAT Telecommands (4)

FE Primitive Telecommands

APID	Function Code	Description
0x648	0	GLT register read
	1	GLT register load
	2	GLT command
	3	TIC register read
	4	TIC register load
	5	TIC command
	6	PDU register read
	7	PDU register load
	8	PDU command
	9	TEM register read
	10	TEM register load
	11	TEM command
	12	CCC register read
	13	CCC register load
	14	CCC command
	15	CRC register read
	16	CRC register load
	17	CRC command
	18	CFE register read
	19	CFE register load

APID	Function Code	Description
0x648	20	CFE command
	21	TCC register read
	22	TCC register load
	23	TCC command
	24	TRC register read
	25	TRC register load
	26	TRC command
	27	TFE register read
	28	TFE register load
	29	TFE command
	30	AEM register read
	31	AEM register load
	32	AEM command
	33	ARC register read
	34	ARC register load
	35	ARC command
	36	AFE register read
	37	AFE register load
	38	AFE command

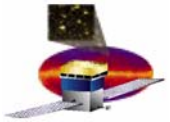
LAT Telecommand Format

- Each telecommand in table has detailed definition
- Example shows File Upload Commit command to place file data contents from file upload buffer to the actual storage device location /ee0/d009/f0000004, which translates to:
  EEPROM partition 0, directory 9, file 4
  (EEPROM partition 0 is specified as file device 2)

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Version = 0			T=1	SH=1	APID = 0x641										
SF = 3			Sequence Count												
Packet Length = 7															
0			Function Code = 2												
File Device = 2			File Directory = 9												
File Number = 4															
Packet Checksum															

Telemetry

- LAT has been allocated a real-time telemetry bandwidth of a 116-byte housekeeping packet 4 times per second
- Translates to an instrument telemetry rate of 3.7 kbps
- Telemetry APIDs not defined yet
- Additional diagnostic telemetry may be commanded up to a limit of 960 byte blocks 4 times per second (including the housekeeping telemetry)
  - Subject to SSR space and downlink bandwidth constraints



Housekeeping and Low Rate Science

- Housekeeping
  - A set of metrics monitoring the health of the LAT
  - Monitored by the SIU
  - Run independently of the event path ("always on")
  - The housekeeping scans collect
    - Instrument: temperatures, voltages, currents, … (via LCB command/response)
    - CPU metrics: idle time, memory usage, … (via LCB CPU-CPU communications)
- Low Rate Science
  - A set of counters which can be multiplexed to test points
  - Controlled and monitored by the SIU
  - Run independently of the event path ("always on")
  - All counters can be started and stopped synchronously
  - Counters can target a variety of information … examples
    - ACD tile singles rates
    - A single tower's three-in-a-row trigger rate

LAT HSK (0)

Description of Instrumentation		Destination of Instrumentation						
		Spacecraft		PDU		TEM	GASU	
Description	Type	SC-Pri	SC-Sec	PDU-A	PDU-B	TEM	GASU-A	GASU-B
ACD Tiles	RTD	5	5					
ACD TSA Shell (outside)	RTD			2	2			
Radiator Anti-Freeze Htr	RTD			4	4			
Radiators	RTD	8	8	10	10			
VCHP's Reservoir Htr	RTD	12	12	24	24			
ACD TSA Shell (inside)	Thermistor	5	5					
ACD BEA-Grid interface	Thermistor			2	2			
ACD PMT Rail	Thermistor	4	4	4	4			
ACD FREE	Thermistor						12	12
Calorimeter Baseplate	Thermistor			16	16			
CAL AFEE	Thermistor					128		
SIU	Thermistor	2	2					
PDU	Thermistor	2	2					
EPU	Thermistor			3	3			
GASU	Thermistor	2	2					
TEM DAQ Board	Thermistor			16	16			
TEM pwr Supply	Thermistor			16	16			
AEM Power Supply	Thermistor						1	1
AEM DAQ Board	Thermistor						1	1
Grid-Radiator interface	Thermistor	4	4	4	4			
Grid Make-up Heaters	Thermistor	4	4					
VCHP-XLHP interface	Thermistor	4	4	12	12			
X-LAT Plate	Thermistor	4	4					
VCHP-DSHP interface	Thermistor			12	12			
Grid	Thermistor			12	12			
TKR Cables	Thermistor					256		
Spare Temp. Channels	Thermistor	8	8					
Total		**64**	**64**	**137**	**137**	**384**	**14**	**14**

LAT HSK (1)

Description of Instrumentation		Destination of Instrumentation						
		Spacecraft		PDU		TEM	GASU	
Description	Type	SC-Pri	SC-Sec	PDU-A	PDU-B	TEM	GASU-A	GASU-B
ACD FREE V	Voltage						12	12
ACD FREE I	Current						1	1
ACD HV (I)	Current						24	24
CAL V	Voltage					48		
CAL I	Current					48		
SIU Pri/Sec 3.3/5V V	Voltage	2	2					
PDU Pri/Sec 3.3V V	Voltage	2	2					
GASU Pri/Sec 3.3/28V/3.3VA V	Voltage	2	2				6	6
EPU 3.3V V	Voltage			4	4			
TEM 3.3V V	Voltage			16	16			
TEM DAQ V	Voltage					16		
TEM DAQ I	Current					16		
VCHP Reservoir Htr Pri/Sec	Voltage	4	4					
TKR V	Voltage					64		
TKR I	Current					64		
LAT SIU Bus V Pri/Sec	Voltage	2	2					
LAT VCHP Bus V Pri/Sec	Voltage	2	2					
Spare Voltage Channels	Voltage	18	18					
Total		32	32	20	20	256	43	43

- **Uniform sampling rate for all LAT HSK allows 1 sample per 8 sec for each sensor**
- **This rate leaves ~1.5 kbps for CPU metrics and LRS**