GLAST Large Area Telescope

Instrument Flight Software
Flight Unit Design Review
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Thermal Control System

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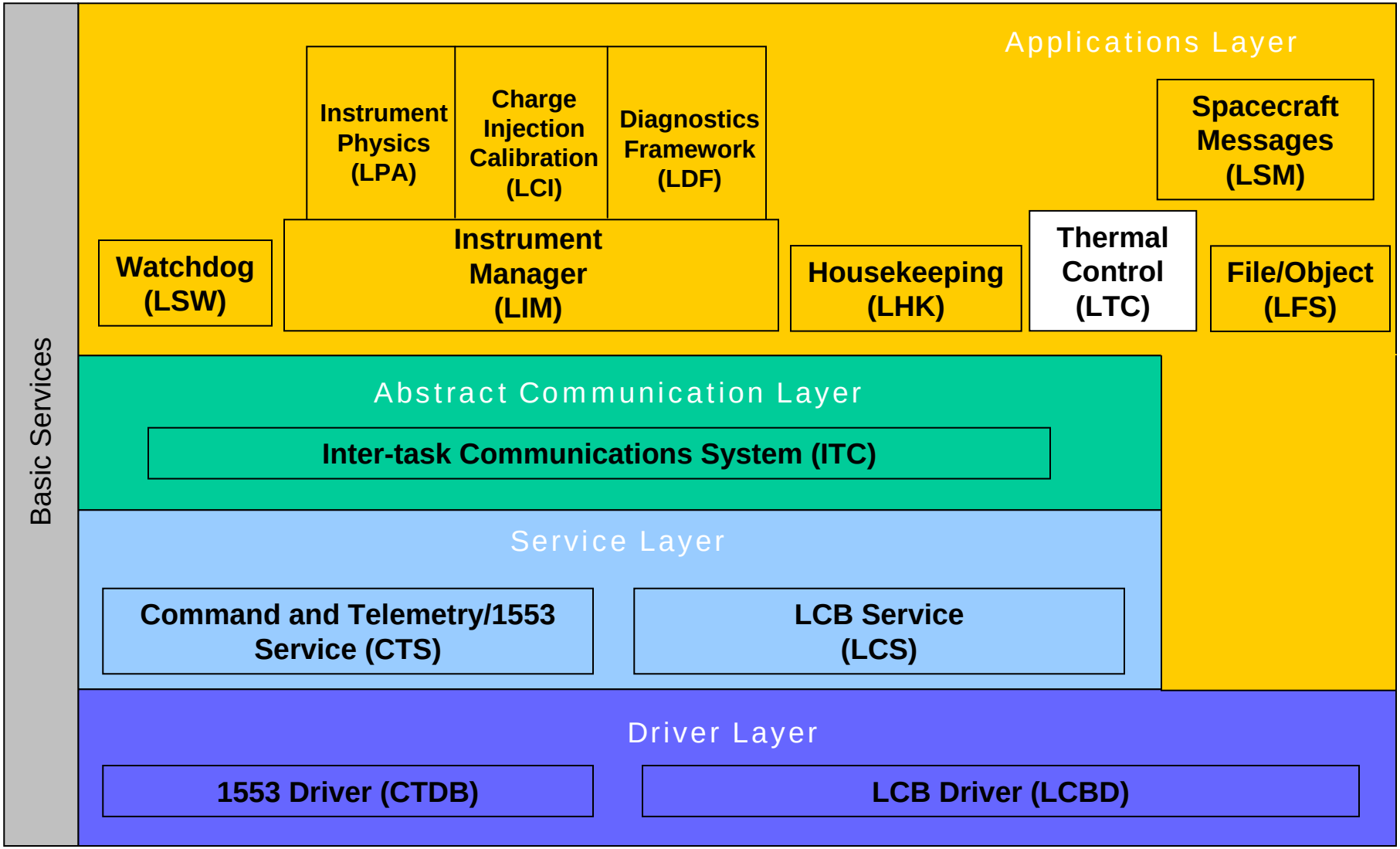
Thermal Control System Requirements

- **Flight Software General Requirements:**
  - **5.3.19.1.1, 5.3.19.1.2, 5.3.19.1.3, 5.3.19.1.5 : The Thermal Control System (TCS) software, running on the SIU, shall be able to load from the file system sensor to ADC mapping information, the set of sensors to be read, the set of sensors to be used in the TCS algorithm, and control parameters for the heat pipes. The files containing this configuration information shall be updatable by telecommand.**
  - **5.3.19.7: The FSW shall ensure that thermal constraints, as defined in The LAT Environmental Specification (LAT-SS-00715), stored onboard and updatable by telecommand, are met prior to enabling power-on of EPUs, TEMs, and TEM power supplies.**
  - **5.3.19.1.4: The Thermal Control System software shall acquire as input to the TCS control algorithm or for telemetry output, raw data from the ADCs.**
  - **5.3.19.2: The TCS software shall initialize active thermal control by identifying the appropriate set of inputs (ADC parameters, active sensors & heaters, control & monitoring parameters).**
  - **5.3.19.3, 5.3.19.4 : TCS shall convert received ADC data into temperature values needed by the control algorithm. TCS shall also filter temperature input for inconsistent values.**
  - **5.3.19.5, 5.3.19.12 The TCS software shall determine whether to turn on or off individual heaters based on the algorithm inputs and then output signals, indicating which heaters should be turned on and which should be turned off, via PCI interface.**

TCS Requirements (Cont'd)

- **Flight Software General Requirements:**
  - **5.3.19.6, 5.3.19.8, 5.3.19.10, 5.3.19.11: The TCS software shall handle telecommands that instruct it to shut down active closed loop control, open the TCS watchdog switch, and stop opening the TCS watchdog switch. TCS shall also handle a load shedding command by ceasing to open the TCS watchdog switch and sending a signal to the spacecraft indicating the action taken.**
  - **5.3.19.9: If survival temperature limits are reached as defined by the LAT Environmental Specification (LAT-SS-00778), stored onboard and updatable by telecommand, the FSW shall stop opening the TCS watchdog switch, turn off the DAQ and FEE, and send a signal to the spacecraft indicating the action taken.**
  - **5.3.19.13: Once per second (pending change, "at least once every 10 seconds"), a telemetry packet shall be composed to monitor the TCS, including: identification of active sensors, identification of active heaters, status for each heat pipe, state information, input temperatures, and algorithm results.**

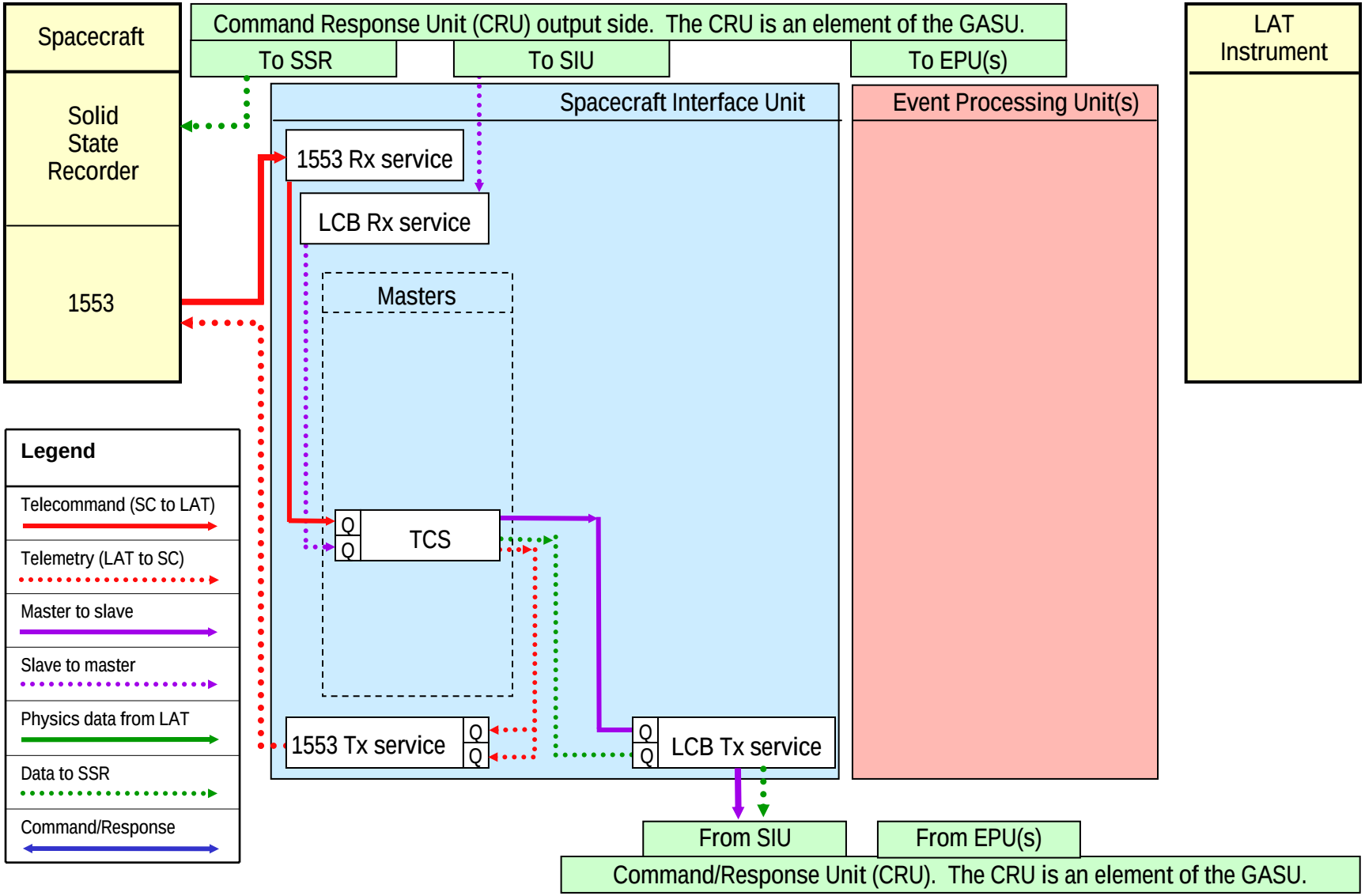
FSW Layer Architecture



TCS Functional Components

- **Functional Inputs**
  - The Thermal Control System receives the following information as table/file inputs:
    - A mapping of sensors to physical ADCs
    - The set of sensors to be read and reported in telemetry
    - The set of sensors to be used in the TCS algorithm (a subset of the sensors to be read)
    - The set of 4 control parameters for each heater pipe: Reservoir Low, Radiator Interface Temperature (RIT) Low Limit, RIT High Limit, and Deadband
  - TCS receives raw data from the analog to digital converters
  - TCS receives telecommands from the Spacecraft
- **Functional Processing**
  - TCS initializes itself from the inputs provided
  - TCS converts received ADC data into temperature values
  - TCS filters/smooths temperature input for bad values
  - TCS decides whether to turn individual heaters on or off based on the inputs
  - TCS evaluates whether specified thermal constraints are met, and that it is safe to power up EPUs, TEMs, and Tower power supplies
  - TCS stops resetting the watchdog in the appropriate circumstances
  - In response to telecommands, TCS may shut itself down, stop resetting the TCS watchdog and, under certain circumstances, shut down the DAQ and front-end electronics
- **Functional Outputs**
  - TCS outputs signals, via PCI interface, indicating which heaters should be turned on and which should be turned off
  - Once per second, TCS generates telemetry packets that report identification of active sensors, identification of active heaters, status for each heat pipe, state information, input temperatures, and algorithm results
    - Pending requirements change to “at least once every 10 seconds”

LAT FSW Architecture (TCS Specific)



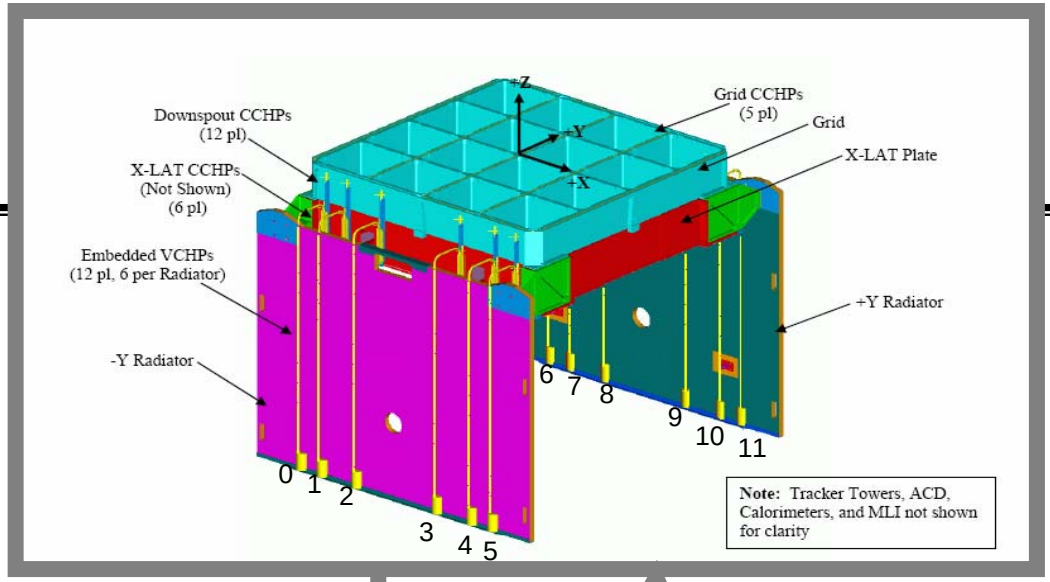
TCS: Physical Elements

- The physical system consists of 12 heater pipes, 6 on each of the GLAST's two radiators.
  - Each heat pipe is equipped with two temperature sensors and one heater controller.
  - The two temperature sensors measure
    - The temperature of the ammonia in the reservoir
    - The Radiator Interface Temperature (RIT).
  - There are two types of sensors, thermistors and resistive temperature devices (RTDs). All the reservoir temperature sensors are of one type, and all the RIT sensors are of another type.

- Both the sensors and activators for the heaters have a primary and a redundant set.
  - The primary sensors are read out by the primary Power Distribution Unit (PDU) and the redundant sensors are readout by the redundant PDU.
  - The readout method is via normal LAT internal (LATp) commands.
  - The heater activators are on the Spacecraft Interface Board (SIB), accessible by SIU by a direct PCI read/write operation.

- Control is exercised by simple turning the heaters on or off at each processing cycle. No proportional control exists.
  - Note that while physically there are primary and redundant heater switches, the SIB provides no individual control; any control signal from the SIB always drives both the primary and redundant heater switches.

HP[0] -Y Rad. VCHP 0
:
HP[5] -Y Rad. VCHP 5
HP[6] +Y Rad. VCHP 0
:
HP[11] +Y Rad. VCHP 5



RIT Monitor – thermistors
RES Temp. Monitor - RTD

Primary/Redundant

PDU

\ 12

SIB

PCI

VCHP Heater
Status (On/Off)

X12/PDU

X12/PDU

VCHP Reservoir Temps

Radiator IFTemps

Thermal Control Software

"On/OFF" VCHP Heater

"Open" VHCP Watch-dog Sw

Configuration Files
- Sensor To ADC Mapping.
- ADC To Temp Param.
- Algorithm Param.
- Control/Monitoring Param

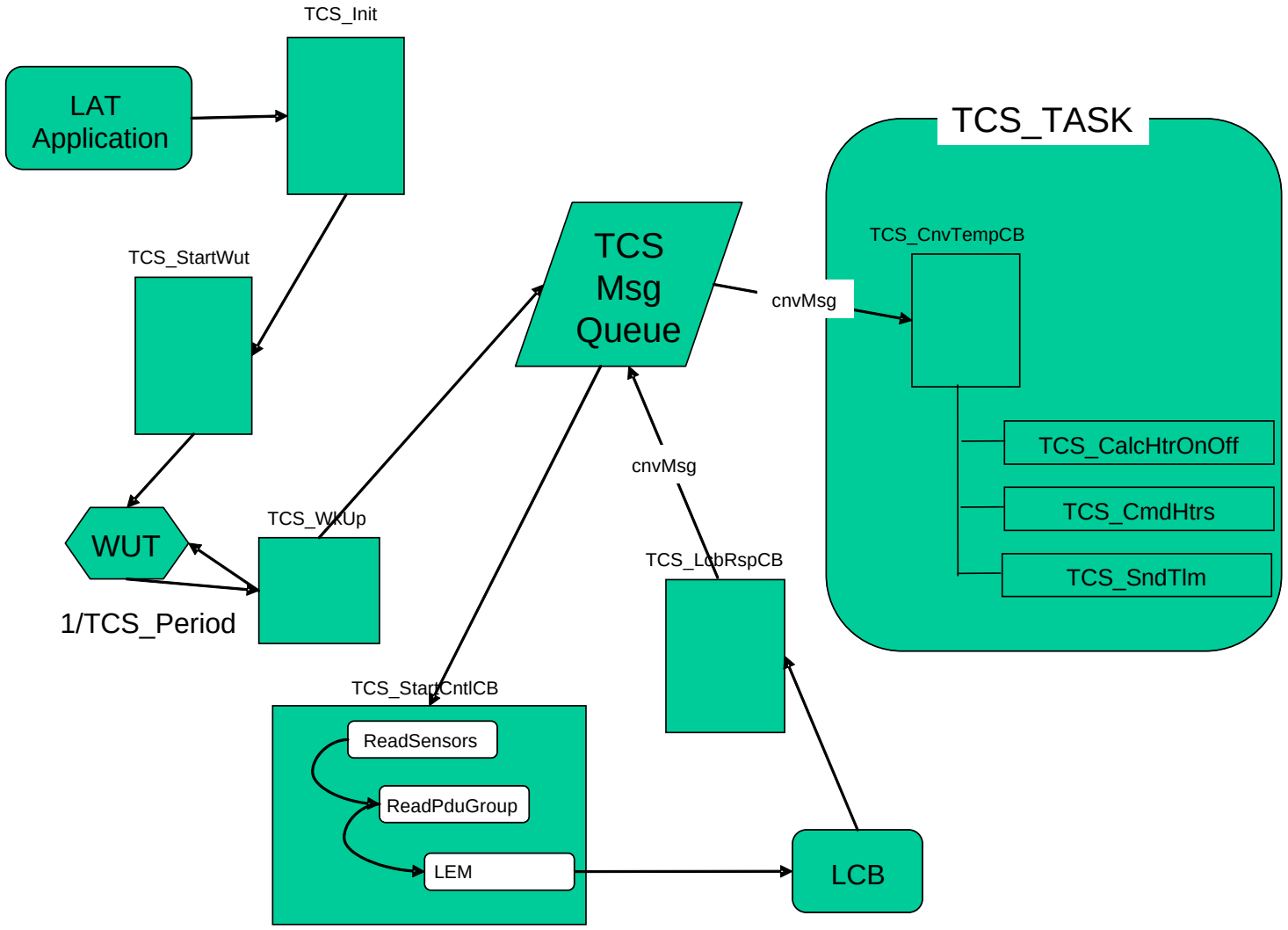
On-board File System

SIU PROCESSOR

Software Components

- **Thermal control is implemented in the LTC package, which is responsible for:**
  - **Managing the configuration parameters. This is includes active sensor specification, the algorithm's parameters, etc.**
  - **Acquiring and preparing the input temperatures**
    - **Reading the ADC values from the PDU**
    - **Converting the ADC readings to Celsius**
    - **Filtering the input temperatures for bad values**
  - **Executing a periodic algorithm that determines whether to turn on the heater or not.**
  - **Resetting the SIB's TCS watchdog timer**
  - **Processing telecommands and issuing telemetry**
  - **Applying the heater element settings by setting bits in the SIB heater control register.**

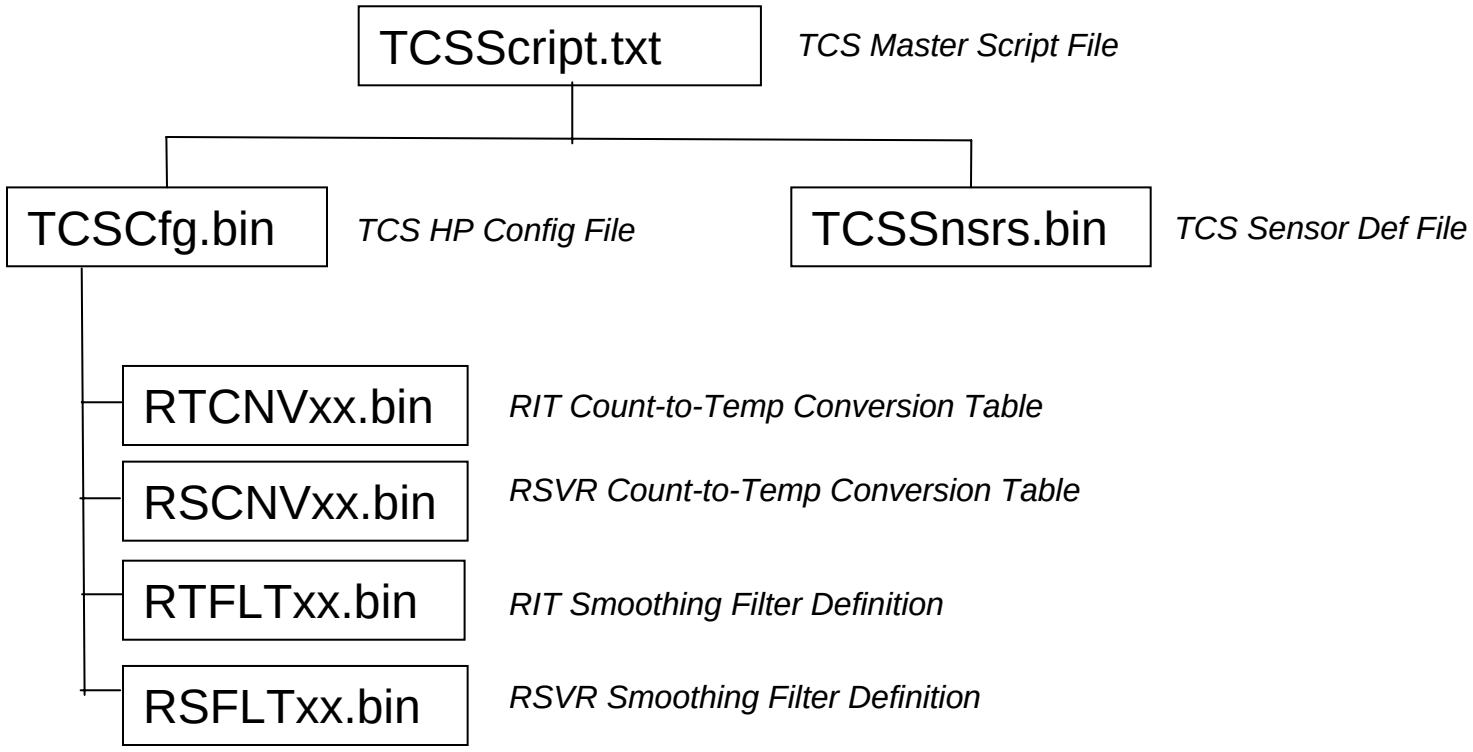
TCS Task Architecture



TCS Configuration

- Configuration information is stored in the on-board file system. These files are updatable by a file upload telecommand. A master file acts as a startup and configuration script.
- Master Startup Script
  - The TCS software reads the master startup script on initialization. The master startup script consists of the names of files containing the following subscripts:
    - File specifying the mapping of the sensors to physical ADCs
    - File specifying the ADC to temperature conversion parameters
    - File specifying the algorithm parameters, includes active sensors and heaters
    - File specifying the TCS control and monitoring parameters.
  - This method allows one to keep a number of alternate subscripts within the file system, using the master startup script as the selection mechanism.
- Before any change can be made to the TCS system, it must be shut down and reinitialized. This process is anticipated to be fast on the scale of the thermal system, so that reinitializing the TCS software will cause no significant perturbation to its functionality.

TCS Input File Structure



Selection of Active Sensors and Heaters

- An input parameter table shall determine which sensors are read and which sensors and heaters are used in the thermal control system algorithm. Note that these are two distinct sets of data maintained in a single table
  - The set of sensors to read
  - The set of sensors and heaters to use in the algorithm
- The second set of sensors must be a proper subset of the first. Sensors that appear only in the first set will be read and reported in the telemetry. Sensors that appear in both will be read and used in the TCS algorithm.
- All sensors are read from the PDU's collection of ADCs using LATp commands. A mapping file is used to construct the LATp commands.

Converting ADC Readings to Temperatures

- **ADC Conversion algorithm**
  - **The raw ADC readings shall be converted to Celsius. This conversion is controlled by a set of parameters stored in the on-board file system.**
  - **The conversion is logically a three-stage process, first converting the ADC counts to a voltage, then converting the voltage to a resistance and finally converting the resistance to a temperature. Thus, there are three sets of parameters to consider:**
    - **The ADC to voltage conversion**
    - **The voltage to resistance conversion**
    - **The resistance to temperature conversion**
  - **In practice, one can combine these three transformations into a single transformation, taking an ADC value directly to a temperature. However, from a maintenance viewpoint, it may prove to be wise to store the transformations separately and combine them during TCS initialization time.**

Filtering the Readings

- **The goal of the filtering process is to produce a representative and believable number for each of the 12 sensor sites. Only active sensors are considered.**
  - **FSW records temperatures from the previous cycle**
  - **Defines what temperature changes are physically impossible for the interval, and thus out of bounds.**

- **The resultant temperature values of working sensors will be subjected to a consistency checking and smoothing algorithm.**

The TCS Algorithm

- Lockheed provides the LAT's FSW team the TCS algorithm in conceptual form. The FSW team translates this algorithm into actual code. The FSW team is responsible for managing and updating this code.
- The algorithm itself is relatively simple
  - It treats each of the 12 sensor/heater pairs as distinct objects; there is no cross-coupling between the elements.
  - Not only are the heat pipes treated in isolation: the same algorithm runs on each of the heat pipes, although with a different set of parameters.
- The algorithm inputs consist of:
  - A set of 4 static but uploadable and updatable parameters controlling the algorithm (reservoir low temp, RIT high temp limit, RIT low temp limit, Deadband)
  - The 12 input working values for the sensors
  - A 12 x 1 bit state vector reflecting the action taken on the previous iteration of the loop

The TCS Algorithm (cont'd)

- The algorithm is executed in a 1 second periodic loop.
- The parameters shall be represented as signed 16 bit quantities, with the upper 8 bits representing whole degrees Celsius and the lower 8 bits representing fractional degrees. This gives a range of –127 to +128 ^{o}C and a precision 1/256 ^{o}C. This affords adequate range and precision.
- The return value of the algorithm is two 12 x 1 bit vectors.
  - One 12 bit vector indicates which heaters should be turned on.
  - The other 12 bit vector keeps track of state information. This state information is passed into the algorithm on the next pass.

TCS Telecommands

- **Telecommands**
  - **Restart - Read configuration files, initialize and start TCS.**
  - **Stop - Stop heater control**
  - **Heater On or Off: Set one or more heat pipe reservoir heaters to always on or off.**

Forward Work

- **Coding is 70% complete**
- **Thermal control (with simulated inputs) will be demonstrated in December 2004**
  - **Final demonstration of functionality and testing can only be performed in thermal vac**
- **Code and unit test complete 12/01/04**

TCS Telemetry

- A telemetry packet shall be composed for the purpose of monitoring the inputs and the actions of the TCS. This packet will be logged to the SSR. The format of the data will be a standard CCSDS header followed by the data.

Size	Content
3 bytes	Active Sensor mask (24 bits)
3 bytes	Active Heater mask (24 bits)
3 bytes	Input status vector, 2 bits for each heat pipe 0 = OK, 1 = 1 Primary Sensor Bad, 2 = Redundant Sensor Bad, 3 = Both Bad
2 bytes	12 bits of state information
36 bytes	Raw ADC values (prior to smoothing) for HP temperature
48 bytes	24 16 bit temperature values representing the input temperature (Heat Pipe 0, reservoir temperature, RIT temperature; Heat Pipe 1, reservoir temperature, RIT temperature).
3 bytes	Algorithm result bit vector (24 bits, 12 state and 12 heater activate bits)

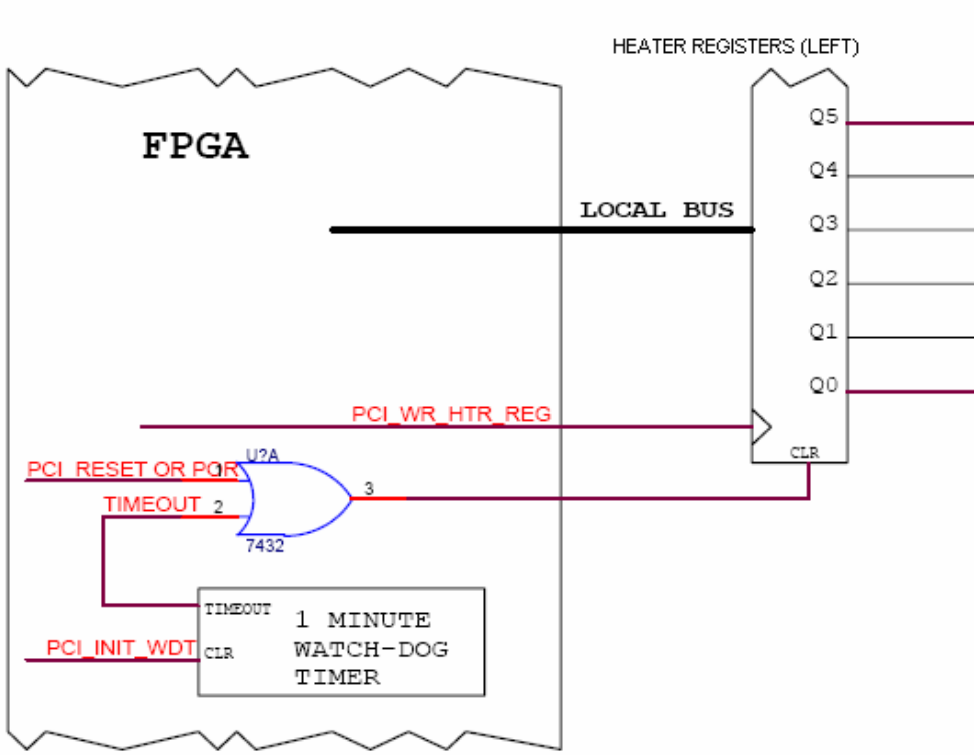
- The maximum size of this packet is 96 bytes + the size of the header. If necessary, this data can be compressed.

GLAST Large Area Telescope

Backup

TCS Watchdog Switch

- **As shown below in the partial block diagram, the SIB board has a watchdog timer overseeing the heater switches. If no write is performed to the heater control register on the SIB board within a 1 minute timeframe, the watchdog activates the heater switches.**



TCS Task Architecture

- **LTC runs as a single task on the SIU. This task is structured as follows:**
  - **LTC uses a wakeup timer to drive execution of the periodic algorithm**
  - **It uses a queue to handle messages through the LAT Communications Board**
  - **Uses memory reads and writes to PCI memory to set registers on the SIB: watchdog, heater control**
  - **It makes use of data structures provided by the command and telemetry tool to implement its command and telemetry packets, packet routing tables, command callbacks, and other infrastructure to communicate over the 1553/CTDB**

TCS Control and Initialization

- **On startup, the TCS task goes through the following general initialization sequence:**
  - **Given configuration data (task priority and execution period), set wakeup timer period**
  - **Set all algorithm history to zero**
  - **Get heater control and SIB watchdog switch addresses**
  - **For each heat pipe, set built-in temp conversion tables, smoothing filter**
  - **Process the master startup script**
  - **Initialize communications over LCB to PDU registers**
  - **Initialize the smoothing filter**
  - **Initialize sensor storage**
  - **Start TCS task**