LAT Flight Software

Thermal Control Software

Number:	LAT-TD-xxx.x
Subsystem:	Data Acquisition/Flight Software
Supersedes:	None
Type:	User Manual
Author:	S. J. Mazzoni
Created:	29 November 2004
Updated:	1 June 2005
Printed:	23 August 2005

This document describes how to use the thermal control software application, LTC.

Document Approval

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Record Of Changes

Version	Date	Title Or Brief Description	Entered By
0.1		Draft Release	

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0 Introduction

This document describes how to load, configure and operate the LAT Thermal Control (LTC) software application.

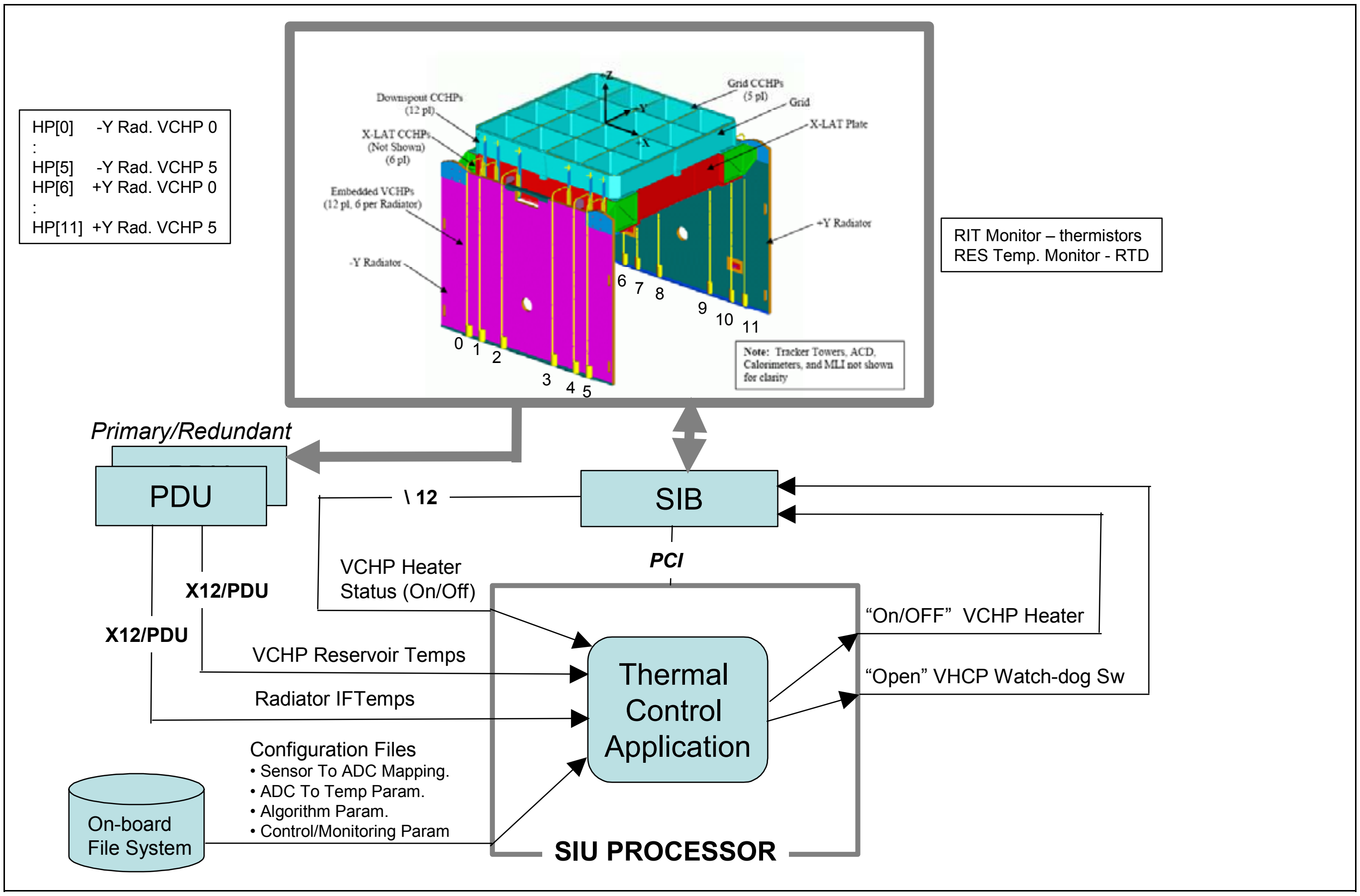
0.0 Document Purpose

This document provides sufficient information to allow LAT operations and test personnel to effectively use LTC.

0.1 Thermal Control (LTC) Overview

Figure 1 shows the major hardware and software components and interfaces used by the LAT Thermal Control application. The LTC application is responsible for controlling the LAT temperature between narrow limits (+/- degrees) to prevent structure distortion during science data collection. Control is accomplished by switching VCHP reservoir heaters on and off to decrease or increase, respectively, the heat conductance of the heat pipes; that is, turning a heater on makes the LAT hotter and turning one off causes the LAT to cool. There are 12 VCHPs residing in the radiator and two sensors per each VCHP. One sensor is located at the radiator interface (RIT) and another located at the VCHP reservoir. The LTC application reads temperature sensor data using the Power Distribution Unit (PDU) and switches the reservoir heaters on and off by writing values into a Storage Interface Borad (SIB) register using the PCI bus. The LTC application is configurable using data file resident on the LAT file system.

Figure 1: LTC Configuration Diagram



0.2 Document Organization

Section 1.0 lists the documents that provide requirements for LTC and that serve as reference material in support of this document.

Section 2.0 describes the architecture of the LTC software and the usage of object files for flight and test.

Section 3.0 describes the LTC configuration files and how to use these files to alter the LTC configuration to meet operational situations.

Section 4.0 describes the telecommands processed by LTC and how to use these commands to alter LTC processing.

Section 5.0 describes the telemetry packet output by LTC.

Section 6.0 describes how to run the Thermal Control software for various test situations.

0.3 Definitions, Abbreviations and Acronyms

Definitions, abbreviations and acronyms use in this document are:

1553 MIL-STD-1553B Bus

ACD Anti-Coincidence Detector

APID Application Identification Number

ARR Automatically Generated Re-point Request

Brd Board

CCSDS Consultative Committee For Spacecraft Data Systems

Also, CCSDS Packet Formatting Software Package

CLI Command Line Interface Software Package

CMX Code Management Tool, eXtra Software Package

Cntrlr Controller

CPU Central Processing Unit

CRU Command Response Unit

CTDB Command and Telemetry Data Bus Software Package

CTS Communication Transport Service Software Package

DAQ Data Acquisition Unit

Dev Development

DMA Direct Memory Access

EBM Event Builder Module

EEPROM Electronically Erasable Programmable Read Only Memory

Envir Environment

EPU Event Processing Unit

FILE LAT File System Software Package

FPGA Field Programmable Gate Array

FSW LAT Flight Software

GASU Global Trigger Anti-collision Spacecraft Unit

GLAST Gamma-ray Large Area Space Telescope

GUI Graphical User Interface

HP Heat Pipe

ITC Inter Task Communication Software Package

LAT Large Area Telescope

LEM LAT Electronics Module Software Package

LHK LAT Housekeeping Software Package

LCAT LAT Command And Telemetry Tool Software Package

LCBD LAT Communication Board Software Package

LCBT LAT Communication Board Test Software Package

LSB Least Significant Bit (20)

LVDS Low Voltage Differential Signal

MSG Message (Error) Tool Software Package

PBC	Primary Boot Code Software Package
PBS	Processor Basic Services Software Package
PC	Personal Computer
PCI	Peripheral Component Interconnect
PDU	Power Distribution Unit
PID	Programmable Interrupt Discrete
PIG	Power Initialization of the GASU Software Package
Pwr	Power
RAD750	RAD750 CPU Borad (Radiation Hardened PowerPC 750)
	Also, Reboot functions and host tools Software Package
RIT	Radiator Interface Temperature
RTOS	Real Time Operating System
SBC	Secondary Boot Code Software Package
SC	Spacecraft
Sci	Science
SIB	Storage Interface Board
Sim	Simulation
SIU	Spacecraft Interface Unit
SLAC	Stanford Linear Accelerator Center
SUPROM	Startup Programmable Read Only Memory
SW	Software
VCHP	Variable Conductance Heat Pipe
VXW	VxWorks Operating System Software Package
ZLIB	Gzip Library Wrapper Software Package

1 Applicable Documents

The documents that provided the system level requirements used to allocate or derive the Thermal Control software requirements are:

1) LAT Flight Software Requirements Document, LAT-SS-00399.

2) LAT Thermal Control Design Document, J. Russell, LAT-SS-02896.

Other reference documents are:

4) Storage Interface Board (SIB) Specification and ICD, 7 February 2004, D. Silver, LAT-SS-15139-01.

5) LAT Flight Software Telemetry and Command Formats, 18 November 2003, D. L. Wood & B. Davis, LAT-TD-02659-01

6) Primary Boot Code (PBC) Design Description, 15 April 2004, D. L. Wood & R.C. Caperoon, D. May, LAT-TD-1806-08

7) Secondary Boot Code (SBC) Design Description, 20 May 2003, D. L. Wood, LAT-TD-2150-04

8) CTDB1553 Drivers Design Description, 3 October 2002, D. L. Wood

9) FILE Package Users Manual, 5 November 2003, D. L. Wood

10) CCSDS Package Users Manual, 1 November 2002, D. L. Wood

11) LAT Housekeeping (LHK) Users Manual, 4 November 2004, S. Maldonado.

12) LCAT Users Manual, 11 February 2004, S. Maldonado.

13) CMX Manual, 15 March 2004, A. P. Waite

14) The Power Distribution Unit Programming ICD Specification, M. Huffer, LAT-TD-01543

Documents 8 through 13 are available on the FSW Website, on the Traveler Documents page: http://www.slac.stanford.edu/exp/glast/flight/web/FSW_traveler.shtml.

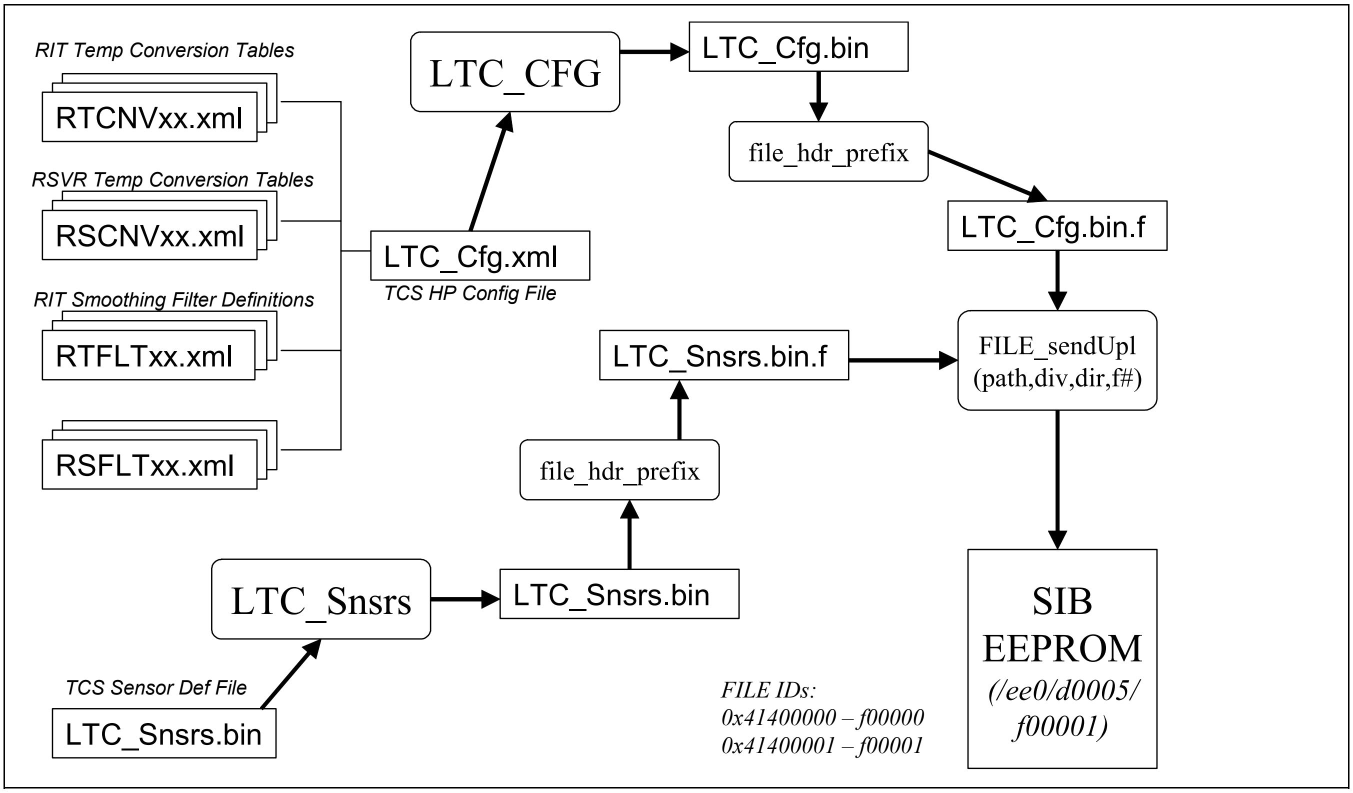
2 LTC Configuration

The LTC software provides an initialization function LTC_Init that is called by the LAT application startup task. LTC_Init reads in two types of configuration files. These files are:

- Heat Pipe Configuration Table
- Sensor Definition

The configuration files are originally defined offline in an XML format, then converted by LTC software tools, *LTC_Cfg* and *LTC_Snsrs*, to a binary format that is consistent with the flight software on-board file system. Figure 2 provides an overview of the organization, relationship and usage of the LTC Configuration files

Figure 2: LTC Configuration Files



2.0 LTC_Init Usage

LTC_Init accepts three arguments that specify the configuration files used by LTC. LTC_Init usage is:

```
    LTC_Init <file_type> <HP_Config_File> <Sensor_Def_File>
```

where

<file_type> specifies the file type, 0 – built-in file, 1 – file specified by path/name, and 2 – file specified by file id code (see FILE package specification). When <file_type> is 0, the other arguments are not used.

<HP_Config_File> specifies the HP configuration file either as the file path/name or FILE system file id depending on the <file_type> value.

<Sensor_Def_File> specifies the Sensor Definition file either as the file path/name or FILE system file id depending on the <file_type> value.

2.1 Heat Pipe Configuration File

The Heat Pipe (HP) Configuration File is an input to the LTC application and provides algorithm control data organized by heat pipe, and other parameters used by LTC that are common to all heat pipes. The structures within the HP Configuration File are:

- Common Parameters Block
- HP Configuration Table
- Temperature Conversion Table

- Smoother Filter Coefficients Array

2.1.0 Common Parameters Block

The Common Parameter Block provides parameters that control LTC processing. These parameters are:

Table 1: Heat Pipe Configuration File, Comment Parameter Block

Parameter	Definition
RITFAIL	The threshold on consecutive bad reads of RIT sensors that is used to declare the sensor broken. The associated heat pipe is set to “always on” or “always off” depending on the HP “fail” parameter from the HP Configuration Table.
RESFAIL	The threshold on consecutive bad reads of reservoir sensors that is used to declare the sensor broken. The associated heat pipe is set to “always on” or “always off” depending on the HP “fail” parameter from the HP Configuration Table.
RITESTTOL	For RIT sensors, the tolerance of the difference between the estimated temperature and the actual temperature for LTC to declare a bad read.
RESESTTOL	For reservoir sensors, the tolerance of the difference between the estimated temperature and the actual temperature for LTC to declare a bad read.

2.1.1 HP Configuration Table

The Heat Pipe (HP) Configuration Table is an input to the LTC application and provides algorithm control data organized by heat pipe. Figure 3 gives an example of an HP Configuration Table. The file will be converted from an XML format to a binary format and uploaded to the onboard file system, to be read whenever LTC starts or is reinitialized. Figure 4 shows an example of the XML for a HP Configuration Table. The LTC software also contains a built-in, hard-coded HP Configuration File that may be used. The controls provided by the HP Configuration File, on an individual heat pipe basis. are:

a) Activate closed loop control, or deactivate closed loop control with reservoir heaters set as always “on” or always “off”.

b) Select RIT input to control algorithm as either DHSP-RIT or X-LAT RIT.

c) Select primary or redundant RIT and reservoir sensors (appropriate PDU must be active) for control.

d) Specify RIT and reservoir temperature conversion tables on a heat pipe basis or on a sensor type (RTD or thermistor) basis.

e) Specify control algorithm parameters on a heat pipe basis.

Figure 3: Example TCS Heat Pipe Configuration Table

HP	Active	Fail	RIT	RIT CNV	RIT FLTR	RES	RES CNV	RES FLTR	RES Lo	Res Hi	RIT Lo	RIT Hi	DELTA
0	YES	ON	DSHP	1	1	P	1	1	-65.0	-64.0	-5.0	-4.0	6.0
1	YES	ON	DSHP	1	1	P	1	1	-65.0	-64.0	-5.0	-4.0	6.0
2	YES	OFF	DSHP	1	1	P	1	1	-65.0	-64.0	-5.0	-4.0	6.0

Figure 3: Example TCS Heat Pipe Configuration Table

HP	Active	Fail	RIT	RIT CNV	RIT FLTR	RES	RES CNV	RES FLTR	RES Lo	Res Hi	RIT Lo	RIT Hi	DELTA
3	NO	ON	DSHP_R	2	1	P	1	1	-65.0	-64.0	-5.0	-4.0	6.0
4	NO	ON	DSHP_R	1	1	P	2	1	-65.0	-64.0	-5.0	-4.0	6.0
5	YES	ON	XLHP_R	1	1	R	2	1	-65.0	-64.0	-5.0	-4.0	6.0
6	YES	ON	DSHP	0	1	P	1	1	-65.0	-64.0	-5.0	-4.0	6.0
7	YES	ON	DSHP	0	1	P	1	1	-65.0	-64.0	-5.0	-4.0	6.0
8	YES	ON	XLHP	3	1	P	0	1	-65.0	-64.0	-5.0	-4.0	6.0
9	YES	OFF	XLHP_R	1	1	P	0	1	-65.0	-64.0	-5.0	-4.0	6.0
10	YES	ON	XLHP	1	1	P	1	1	-65.0	-64.0	-5.0	-4.0	6.0
11	YES	ON	XLHP	1	1	P	1	1	-65.0	-64.0	-5.0	-4.0	6.0

The HP Configuration file fields are:

Table 2: Tags from the Heat Pipe Configuration File

Tag	Description	Example
HP	Number for heat pipe to reflect location on LAT. n, 0 - 5 refers to heat pipes on the LAT –Y radiator with n increasing from LAT –X to +X, and 6 - 11 refers to heat pipes on the LAY +Y radiator with n increasing from LAT +X to -X. This is a required field.	<HP>n</HP
Active	The value “YES” specifies active closed loop control of the heat pipe. The value NO specifies no active closed loop control, and use the Fail column to set heater permanently “off” or “on”. The default is YES.	<ACTIVE>YES</ACTIVE>
Fail	Specifies the action to take if the heat pipe is specified as inactive via the configuration table or declared inactive because all sensors have failed or control software initializing (smoothing filters, etc). The value “ON” specifies to keep the reservoir heater “on”, which eventually stops heat dissipation. The value “OFF” setting specifies keep the reservoir heater “off”, which eventually allows maximum heat dissipation. The default is “ON”	<FAIL>ON</FAIL>

Table 2: Tags from the Heat Pipe Configuration File

Tag	Description	Example
RIT	Specifies the type of the Radiator Interface Temperature (RIT) sensor for use as input to the control algorithm. XLHP specifies the X-LAT RIT sensor and DSHP specifies the DSHP RIT sensor associated with this heat pipe. Either name suffixed with a _R indicates use the redundant sensor (redundant PDU must be on). The default is DSHP. In the event, the specified RIT sensor fails the system shall automatically try to use a backup RIT. Note: The RIT Cnv column that defines the count to temperature conversion file may need to be changed for valid readings from the specified RIT sensor.	<RIT>DSHP</RIT>
RIT Cnv	Specifies n the index or file suffix for the sensor conversion binary file used as input to TCS for converting the RIT sensor counts to temperature Celsius. The file name is RTCNV0n.bin with 0s filled as necessary to get a seven character name. This file is produced as described in the “Temperature Conversion Files” section of this document. A 0 in this field means to use the default thermistor conversion table built into the TCS software.	<RITCNV>1</RITCNV>
RIT FLTR	Specifies n the index or file suffix for the filter file used as input to TCS for establishing the FIR filter for the RIT sensor inputs. The file name is RTFLT0n.bin with 0s filled as necessary to get a seven character name. This file is produced as described in the “Temperature Conversion Files” section of this document.	<RITFLT>1</RITFLT>
RES P/R	Specifies to use a primary or redundant sensor for heat pipe reservoir sensor. The PDU that accesses this sensor must be turned on (the primary and redundant sensors are on different PDUs). The default is P.	<RES>P</RES>
RES Cnv	Specifies n the index or file suffix for the sensor conversion binary file used as input to TCS for converting the reservoir heater sensor counts to temperature Celsius. The file name is RSCNV00n.bin with 0s filled as necessary to get a seven character name. This is file is produced as described in the “Temperature Conversion Files” section of this document. A 0 in this field means to use the default RTD conversion table built into the TCS software.	<RESCNV>1</RESCNV>

Table 2: Tags from the Heat Pipe Configuration File

Tag	Description	Example
RES FLTR	Specifies n the index or file suffix for the filter file used as input to TCS for establishing the FIR filter for the reservoir heater sensor inputs. The file name is RSFLT0n.bin with 0s filled as necessary to get a seven character name. This file is produced as described in the “Temperature Conversion Files” section of this document.	<RESFLT>1</RESFLT>
RES Lo	Reservoir low temperature limit used by the TCS Control Algorithm. The TCS algorithm will turn the reservoir heater “on” when the reservoir temperature drops below this value. When the reservoir temperature is above this value, the heater is turned on if the reservoir temperature is below the RES Hi limit and the heater was command on the previous cycle. The RES Lo and Res Hi parameters provide antifreeze protection for the reservoir.	<RESLo>-65.0</RESLo>
RES Hi	Reservoir high temperature limit used by the TCS Control Algorithm. The TCS algorithm will turn the reservoir heater “on” when the reservoir temperature drops below this value and the heater was command on the previous cycle. When the reservoir temperature is above this value, the heater is turned “on” or “off” depending on the RIT for the heat pipe.	<RESHi>-64.0</RESHi>
RIT-Lo	RIT low temperature limit used by the TCS Control Algorithm to turn the heater “on” or “off”. The TCS control algorithm tries to keep the RIT between the RIT-Lo and RIT-Hi limits providing the difference between the RIT and the reservoir temperature is greater than DELTA.	<RITLo>-5.0</RITLo>
RIT-Hi	RIT high temperature limit used by the TCS control algorithm to turn the heater “on” or “off”. The TCS control algorithm tries to keep the RIT between the RIT-Lo and RIT-Hi limits providing the difference between the RIT and the reservoir temperature is greater than DELTA.	<RITHi>-4.0</RITHi>
DELTA	Limit for the difference between the RIT and the HP reservoir temperature. The TCS control algorithm will not turn “on” the HP reservoir heater unless the difference between the RIT and the reservoir temperature is greater than DELTA.	<DELTA>6.0</DELTA>

An example HP Configuration file in XML format is listed below. It shows only two heat pipes, but the operational version will provide data for 12 heat pipes.

Figure 4: Example LTC HP Configuration Table (XML Definition)

```
<?xml version="1.0"?>

<!-- File Name: LTCCfg.xml -->
```

Figure 4: Example LTC HP Configuration Table (XML Definition)

```
<LTC_CONFIGURATION>
<COMMON>
<RITFAIL>5</RITFAIL>
<RESFAIL>5</RESFAIL>
<RITESTTOL>1.0</RITESTTOL>
<RESESTTOL>2.0</RESESTTOL>
</COMMON>
<HEAT_PIPE>
<HP>0</HP>
<ACTIVE>YES</ACTIVE>
<FAIL>OFF</FAIL>
<RIT>DSHP</RIT>
<RTCNV>1</RTCNV>
<RTFLT>1</RTFLT>
<RES>P</RES>
<RSCNV>1</RSCNV>
<RSFLT>2</RSFLT>
<RESLo>-65.0</RESLo>
<RESHi>-64.0</RESHi>
<RITLo>-5.0</RITLo>
<RITHi>-4.0</RITHi>
<DELTA>6.0</DELTA>
</HEAT_PIPE>
<HEAT_PIPE>
<HP>1</HP>
<ACTIVE>YES</ACTIVE>
<FAIL>OFF</FAIL>
<RIT>XLHP</RIT>
<RTCNV>1</RTCNV>
<RTFLT>1</RTFLT>
<RES>R</RES>
<RSCNV>1</RSCNV>
<RSFLT>1</RSFLT>
<RESLo>-65.0</RESLo>
<RESHi>-64.0</RESHi>
<RITLo>-5.0</RITLo>
<RITHi>-4.0</RITHi>
<DELTA>6.0</DELTA>
</HEAT_PIPE>
</LTC_CONFIGURATION>
```

2.1.2 Temperature Conversion Table

A temperature conversion table provides a table for each sensor to convert ADC counts to temperature in Celsius. The same table may be specified using the HP Configuration file described above for more than one sensor. A linear interpolation is performed by the LTC software to calculate Celsius temperature values from sensor ADC counts. The table values are obtained from the manufacturers of the thermistor used to measure RIT and reservoir temperatures.

These values are put into XML format in a separate file from the HP Configuration File (See Figure 1.0), and then converted to binary structure. The binary representation of the temperature conversion tables is stored as part of the HP Configuraiton file.

The elements of the LTC Temperature Conversion Table are:

Table 3: Tags from the Temperature Conversion File

Tag	Description	Example
ADC Counts	Sensor ADC count for the corresponding Celsius temperature.	<ADC_COUNT>100</ADC_COUNT>
Temperature	Temperature in Celsius for the corresponding ADC count.	<CELSIUS>-4.0</CELSIUS>

An example Temperature Conversion Table is depicted in Figure 5.

Figure 5: Example Temperature Conversion Table

ADC Counts	Temperature Celsius
100	-120.0
150	-110.0
200	-100.0
400	-80.0
1000	-40.0
1800	0.0
2200	20.0
2500	40.0
2800	60.0
3300	100.0
4000	120.0

An example of the Temperature Conversation file in XML format is show below.

Figure 6: Example Temperature Conversion Table (XML Definition)

```
<?xml version="1.0"?>

<!-- File Name: RSCNV01.xml -->

<TMP_CNV_TBL>

<CNV>
<ADC_COUNT>100</ADC_COUNT>
<CELSIUS>-120.0</CELSIUS>
</CNV>
<CNV>
<ADC_COUNT>150</ADC_COUNT>
<CELSIUS>-110.0</CELSIUS>
</CNV>
<CNV>
<ADC_COUNT>200</ADC_COUNT>
<CELSIUS>-100.0</CELSIUS>
```

Figure 6: Example Temperature Conversion Table (XML Definition)


```
</CNV>
<CNV>
<ADC_COUNT>400</ADC_COUNT>
<CELSIUS>-80.0</CELSIUS>
</CNV>
<CNV>
<ADC_COUNT>1000</ADC_COUNT>
<CELSIUS>-40.0</CELSIUS>
</CNV>
<CNV>
<ADC_COUNT>1800</ADC_COUNT>
<CELSIUS>0.0</CELSIUS>
</CNV>
<CNV>
<ADC_COUNT>2200</ADC_COUNT>
<CELSIUS>20.0</CELSIUS>
</CNV>
<CNV>
<ADC_COUNT>2500</ADC_COUNT>
<CELSIUS>40.0</CELSIUS>
</CNV>
<CNV>
<ADC_COUNT>2800</ADC_COUNT>
<CELSIUS>60.0</CELSIUS>
</CNV>
<CNV>
<ADC_COUNT>3300</ADC_COUNT>
<CELSIUS>100.0</CELSIUS>
</CNV>
<CNV>
<ADC_COUNT>4000</ADC_COUNT>
<CELSIUS>120.0</CELSIUS>
</CNV>

</TMP_CNV_TBL>
```


2.1.3 Smoothing Filter Table

A smoothing filter table provides an array of filter coefficients for each sensor to smooth ADC counts prior to conversion to Celsius. The coefficient array may be specified using the HP Configuration file described above for more than one sensor. The binary representation of the smoothing coefficient array is stored as part of the HP Configuration file.

Figure 7: Example LTC Smoothing Filter Array

Coefficient
.5238
.3810
.2381
.0952
-.0476
-.1905

Figure 8 below shows an example XML file defining LTC smoothing filter coefficients. The XML file is read, converted to binary and embedded into the binary HP Configuration file by the program *LTC_Cfg*.

Figure 8: LTC Smoothing Coefficients (XML Definition)

```
<?xml version="1.0"?>

<!-- File Name: RESFLT01.xml -->

<LTC_FILTER_COEFF>

<COEFF>.5238</COEFF>
<COEFF>.3810</COEFF>
<COEFF>.2381</COEFF>
<COEFF>.0952</COEFF>
<COEFF>-.0476</COEFF>
<COEFF>-.1905</COEFF>

</LTC_FILTER_COEFF>
```

2.2 LTC Sensor Definition File

The LTC software at initialization inputs a sensor definition file that defines for the primary and redundant PDUs, the group and ADC number for each sensor used by LTC, and associates each sensor with a particular heat pipe on the LAT. The file contains two Sensor Definition tables, one for the primary PDU and the other for the redundant PDU. There is a default file compiled into the LTC software so this file is not mandatory. The file will be converted from an XML format to a binary format and uploaded to the onboard file system, and read whenever LTC starts or is restarted.

The Sensor Definition Table columns (and tags for the XML specification) are:

Table 4: Tags from the Sensor Definition File

Tag	Description	Example
PRIMARY PDU	Specifies the table for the Primary PDU. The primary PDU is declared as PDU 0 by the LAT software.	<TYPE>PRIMARY PDU</RITLo>

Table 4: Tags from the Sensor Definition File

Tag	Description	Example
HP#	Heat pipe number associated with this sensor that locates the heat pip on the LAT. Numbers 0 - 5 refer to heat pipes on the LAT –Y radiator increasing from LAT –X to +X, and 6 - 11 refer to heat pipes on the LAY +Y radiator increasing from LAT +X to -X.	<HP>n</HP>
Sensor Name	Specifies the name assigned to the sensor in the PDU Interface Document (LAT-DS-01743).	<NM>+Y_VCHP_RSVR_HTR_T_0</NM>
Group	Specifies the PDU group number assigned to the sensor in the PDU Interface Document (LAT-DS-01743). The PDU employs eight ADC groups numbered 0 - 7.	<GRP>2</GRP>
ADC #	Specifies the PDU ADC number assigned to the sensor in the PDU Interface Document (LAT-DS-01743). The PDU employs twenty-one ADCs per group numbered 0 – 20.	<ADC>10</ADC>

Figure 2.0 gives an example of a Sensor Definition Table for the primary PDU.

Table 5: Sample Sensor Definition Table for Primary PDU

PRIMARY PDU			
HP#	**Sensor Name**	**Group**	**ADC #**
6	+Y_VCHP_RSVR_HTR_T_0	2	10
7	+Y_VCHP_RSVR_HTR_T_1	3	10
8	+Y_VCHP_RSVR_HTR_T_2	4	10
9	+Y_VCHP_RSVR_HTR_T_3	5	10
10	+Y_VCHP_RSVR_HTR_T_4	6	10
11	+Y_VCHP_RSVR_HTR_T_5	7	10
0	-Y_VCHP_RSVR_HTR_T_0	2	12
1	-Y_VCHP_RSVR_HTR_T_1	3	12
2	-Y_VCHP_RSVR_HTR_T_2	4	12
3	-Y_VCHP_RSVR_HTR_T_3	5	12
4	-Y_VCHP_RSVR_HTR_T_4	6	12
5	-Y_VCHP_RSVR_HTR_T_5	7	12
6	+Y_VCHP_DSHP_INTF_T_0	4	7
7	+Y_VCHP_DSHP_INTF_T_1	5	7
8	+Y_VCHP_DSHP_INTF_T_2	6	7

Table 5: Sample Sensor Definition Table for Primary PDU

9	+Y_VCHP_DSHP_INTF_T_3	7	7
10	+Y_VCHP_DSHP_INTF_T_4	0	8
11	+Y_VCHP_DSHP_INTF_T_5	1	8
0	-Y_VCHP_DSHP_INTF_T_0	2	8
1	-Y_VCHP_DSHP_INTF_T_1	3	8
2	-Y_VCHP_DSHP_INTF_T_2	4	8
3	-Y_VCHP_DSHP_INTF_T_3	5	8
4	-Y_VCHP_DSHP_INTF_T_4	6	8
5	-Y_VCHP_DSHP_INTF_T_5	7	8
6	+Y_VCHP_XLHP_INTF_T_0	2	14
7	+Y_VCHP_XLHP_INTF_T_1	3	14
8	+Y_VCHP_XLHP_INTF_T_2	4	14
9	+Y_VCHP_XLHP_INTF_T_3	5	14
10	+Y_VCHP_XLHP_INTF_T_4	6	14
11	+Y_VCHP_XLHP_INTF_T_5	7	14
0	-Y_VCHP_XLHP_INTF_T_0	2	15
1	-Y_VCHP_XLHP_INTF_T_1	3	15
2	-Y_VCHP_XLHP_INTF_T_2	4	15
3	-Y_VCHP_XLHP_INTF_T_3	5	15
4	-Y_VCHP_XLHP_INTF_T_4	6	15
5	-Y_VCHP_XLHP_INTF_T_5	7	15

3 LTC Telecommands

The LTC application accepts the telecommands to provide control during and telemetry interface as described in this section. The telecommands are defined using the LCAT tool that generates source files for the LTC software and ITOS files for use with the spacecraft GUI.

3.0 Telecommands

The commands from the spacecraft processed by the LTC package are (SDIS mnemonics):

1) LTC Restart (LTCRESTART)
2) LTC Start (LTCSTART)
3) LTC Stop (LTCSTOP)
4) LTC Set Mode (LTCSETMODE)
5) LTC Heater On, Off or Control (LTCHTRONOFFCNTL)
6) LTC Set Control Parameters (LTCSETPARAM)
7) LTC Set Telemetry Frequency (LTCSETTLMFREQ)

3.0.0 LTC Restart (LTCRESTART)

The LTC Restart telecommand is sent from the spacecraft to the LAT to restart LTC using the specified configuration files. The LTC Restart command parameters are: File_Type specifies files are given by name (test only), or by file id; HP_Cfg_File_Id specifies the HP Configuration File; and, Sensor_Def_File_Id specifies the Sensor Definition File. The LTC Restart telecommand format is:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0			**1**	**1**	**LTC APID = 0x645**										
3		**Sequence Count**													
Packet Length = 13															
0	**Function Code = 1**														
File_Type															
Hp_Cfg_File_Id (MSW)															
Hp_CFG_File_Id (LSW)															
Snsr_Def_File_Id (MSW)															
Snsr_Def_File_Id (LSW)															
Packet Checksum															

3.0.1 LTC Start (LTCSTART)

The LTC Start telecommand is sent from the spacecraft to the LAT to start LTC periodic processing either in active or passive mode. The Active_Passive command parameter is 1 for active and 2 for passive. LTC in active mode sends commands to the HP reservoir heater switches, or in passive mode LTC does all its processing but bypasses sending commanding the heater switches. The LTC Start telecommand format is:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0			**1**	**1**	**LTC APID = 0x645**										
3		**Sequence Count**													
Packet Length = 5															
0	**Function Code = 2**														

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Active_Passive															
Packet Checksum															

3.0.2 LTC Stop (LTCSTOP)

The LTC Stop telecommand is sent from the spacecraft to the LAT to stop LTC periodic processing. The LTC Stop command format is:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0			**1**	**1**	**LTC APID = 0x645**										
3		**Sequence Count**													
Packet Length = 3															
0	**Function Code = 5**														
Packet Checksum															

3.0.3 LTC Set Mode (LTCSETMODE)

The LTC Set Mode telecommand is sent from the spacecraft to the LAT to set the LTC processing mode to either in active or passive mode. The Active_Passive command parameter is 1 for active and 2 for passive. LTC in active mode sends commands to the HP reservoir heater switches, or in passive mode LTC does all its processing but bypasses sending commands to the heater switches. The LTC Set Mode telecommand format is:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0			**1**	**1**	**LTC APID = 0x645**										
3		**Sequence Count**													
Packet Length = 5															
0	**Function Code = 4**														
Active_Passive															
Packet Checksum															

3.0.4 LTC Heater On, Off or Control (LTCHTRONOFFCNTL)

The LTC Heater, On, Off or Control telecommand is sent from the spacecraft to the LAT to instruct LTC to command a specified heater switch to always on, to always off or to automatic control. The LTC Restart command parameters are: Heater_Number specifies the heater number (0-11); and, On_Off_Cntl specifies the control mode as 0-Off, 1-On and 2-Control. The LTC Heater On, Off or Control telecommand format is:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0			**1**	**1**	**LTC APID = 0x645**										
3		**Sequence Count**													
Packet Length = 7															
0	**Function Code = 4**														
Heater_Number															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
On_Off_Cntl															
Packet Checksum															

3.0.5 LTC Set Control Parameters (LTCSETPARAM)

The LTC Set Control Parameters telecommand is sent from the spacecraft to the LAT to modify the LTC control algorithm parameters. The LTC Set Control Parameters command parameters are: Hp_Sel_Mask selects the heaters getting the new control parameters (2n = 1 selects heater n); Res_Lo (float) specifies the low limit in Celsius for the heater reservoir temperature; Res_Hi (float) specifies the high limit in Celsius for the heater reservoir temperature; Rit_Lo (float) specifies the low limit in Celsius for the radiator interface temperature (RIT); Rit_Hi (float) specifies the high limit in Celsius for the radiator interface temperature (RIT); and, Db_Delta specifies the deadband delta (RIT minus reservoir) temperatrure in Celsius. The LTC Set Control Parameters telecommand format is:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0			**1**	**1**	**LTC APID = 0x645**										
3		**Sequence Count**													
Packet Length = 25															
0	**Function Code = 6**														
Hp_Sel_Mask															
Res_Lo (MSW)															
Res_Lo (LSW)															
Res_Hi (MSW)															
Res_Hi (LSW)															
Rit_Lo (MSW)															
Rit_Lo (LSW)															
Db_Delta (MSW)															
Db_Delta (LSW)															
Packet Checksum															

3.0.6 LTC Set Telemetry Frequency (LTCSETTLMFREQ)

The LTC Set Telemetry Frequency telecommand is sent from the spacecraft to the LAT to specify the LTC telemetry output frequency. The LTC Set Telemetry Frequency telecommand parameters are: Tlm_Freq specifies the telemetry frequency in LTC processing cycles, e.g. 0 is no LTC telemetry and 2 would be a telemetry packet every other processing cycle. LTC starts with no telemetry. The LTC Set Telemetry Frequency telecommand format is:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0			**1**	**1**	**LTC APID = 0x688**										
3		**Sequence Count**													
Packet Length = 5															
0	**Function Code = 6**														
Tlm_Freq															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Packet Checksum															

4 LTC Telemetry

LTC outputs a single diagnostic telemetry packet at a frequency as requested by telecommand. Telemetry is off and unless a telecommand is received that sets the telemetry frequency value to one or greater. The LCAT tool is used to build the ITOS files and source code for the LTC telemetry structure. The screen shot in Figure 4.0 shows the LTC diagnostic telemetry packet. The LTC telemetry data is:

1) Selected sensors used for control.
2) Status of sensor input to the control algorithm.
3) Active Heat Pipes
4) Raw ADC values for all sensors read by LTC
5) RIT and reservoir temperature values in Celsius used for control.
6) Heater commands for current cycle.

4.0 LTC Diagnostic Telemetry Packet

The Diagnostic Telemetry packet is described in **Table 6**.

Table 6: LTC Diagnostic Telemetry Packet

Byte Offset	Name	Entry #Bits	Description
14	ResRitSensorSel[12]	16	Specifies the sensors selected for input to the control algorithm for each heat pipe. Each entry is 16-bits with four 4-bit fields and there are 12 entries. Entry n is for heat pipe n. The bit fields for each entry are; Bits 15 – 12: HP number for resevoir sensor. Bits 11 – 8: Type (4-primary or 3-redundant) of resevoir sensor. Bits 7 – 4: HP number for RIT sensor. Bits 3 – 0: Type (0-DSHP Primary, 1-DSHP Redundant, 2-XLHP Primary or 3-XLHP Redundant)
38	ResRitStatus[12]	8	Specifies the current status of the reservoir and RIT sensor input for each heat pipe. Entry n is the status for heat pipe n. Status values are: 0 – Not read, 1 – Good read, 2 – Bad read, and 3 – Designated as broken. Bits 7 – 4: Reservoir sensor status. Bits 3 – 0: RIT sensor status.
50	ActiveHtPipe	16	Bit mask that specifies whether each heat is actively controlled (1) or not controlled (0). Bit n is for heat pipe n, where n is 0 through 11.
52	RawAdcStatVal[72]	16	Read status and raw counts for all sensors read by LTC as defined by the Sensor Defintion file. There are six values per heat pipe for each of the six sensor types associated with a heat pipe by the Sensor Definition Table. The six sensor types are: 0-DSHP Primary, 1-DSHP Redundant, 2-XLHP Primary, 3-XLHP Redundant, 4-Reservoir Primary and 5-Reservoir Redundant. Each entry has the status in Bits 15-12 and the ADC counts in Bits 11-0. Entries 0 – 5 are for heat pipe 0, entries 5 – 11 are for heat pipe 1, etc.
196	TempCelsius[24]	16	Smoothed temperature in Celsius for the reservoir and RIT sensors for each of the 12 heat pipes. The first twelve are for RIT sensors and the second twelve are for the reservoir sensors. The groups are ordered by increasing heat pipe number. The values are fixed point with 8 bit scaling, i.e. divide by 256 to get value.

Table 6: LTC Diagnostic Telemetry Packet

Byte Offset	Name	Entry #Bits	Description
244	ritLo	16	Low limit for RIT termperature for each heat pipe 0 – 11, Celsius scaled by 256.
268	ritHi	15	High limit for RIT termperature for each heat pipe 0 – 11, Celsius scaled by 256
292	resLo	16	Low limit for reservoir termperature for each heat pipe 0 – 11, Celsius scaled by 256
316	resHi	16	High limit for reservoir termperature for each heat pipe 0 – 11, Celsius scaled by 256
340	dbDelta	15	Dead band delta termperature for each heat pipe 0 –11. Celsius scaled by 256.
364	HeaterCmdMask	16	Heater command mask that shows the on (1) or off (0) command from the last LTC cycle (opposite of command bits for SIB Heater Control Register). Bit n is the on/off command for heat pipe n.

5 LTC Software Operation

The constituents of the LTC software package are:

- Thermal control application that operates in a VxWorks embedded and Unix/Linux host environments
- Test programs used for simulating hardware responses
- Programs for generating configuration files form XML files

5.0 Thermal Control Application

LTC operates in several computer configurations to support operational and test situations. These configurations are:

- LAT processing environment
- Test using twoembedded processors
- Test using Unix/Linux host processors
- LTC Executing In LAT Processing Environment

5.0.0 LAT Processing Environment

There are two functions calls to start the LTC application:

LTC_Init(2, 1, <HP_Cfg_File_Id>, <Snsr_Def_File_If>)

LTC_Start( );

Instead of executing the LTC_Start function, the LTC_Start telecommand may be sent after the LTC_Init function is called.

5.0.1 Test Using Two Embedded Processors

The spacecraft side is implemented using an MV2304. After loading the required software, the commands are:

SCP_init 3 // start 1553 interface

PBC_sendBoot 0,1,1,1 // start SBC

Telecommands may be sent from the spacecraft side. LTC_Help lists the telecommands. Also use FILE_sendUPI to upload configuration files to the SIB.

The RAD750 is used to implement the LAT processing. After loading the required software, the command are:

LCP_init( ) // LTC version of LCP

LTC_Init(0,1,0,0) or LTC_Init(2, 1, <HP_Cfg_File_Id>, <Snsr_Def_File_If>) // Initiallizes LTC

LTC_StartTask() // Starts LTC periodic processing

5.0.2 Test Using Unix/Linux Hosts

The commands for running with two host processes are:

<u>LAT Side</u>

LTC_LCP

LCP_init

<u>Spacecraft Side</u>

LTC_SCP

SCP_init <LAT network name>

<u>LAT Side</u>

LTC_Init 0 0 0 or LTC_Init 1 xx yy, where xx and yy are suffixes for the HP configuration file and the Sensor Definition file, e.g. LTC_Cfgxx and LTC_Snsryy.

5.1 Hardware Response Simulator

The LTC package contains the constituent ltc_sim that provides stubs for hardware interface routines. This library is automatically linked with the ltc flight code for the sun-gcc and linux environments. It also may be loaded instead of the LCBD and SIB for the embedded environment.

5.2 Converting Configuration Files

The LTC package provides two programs that run on the Unix/Linux host environment to convert configuration files from XML to a binary file that is uploaded to the LAT onboard storage. These offline programs are:

- *LTC_Cfg*: Converts HP Configuration, Temperature Conversion and Filter Coefficient files from XML to binary.
- *LTC_Snsrs*: Converts Sensor Definition XML file to binary for uploading to the LAT onboard storage.

5.2.0 Usage for the LTC_Cfg Tool

The LTC_Cfg program converts a HP Configuration, Temperature Conversion and Filter Coefficient XML files to the binary HP Configuration file for uploading to the LAT onboard file system. LTC_Cfg usages are:

```
LTC_Cfg <HP_Config_XML_File> <HP_Config_File>
```

Converts file the XML file given by <HP_Config_XML_File> to the binary file as given by <HP_Config_File>. The Temperature Convesion XML files RTCNVxx.XML and RSCNVxx.XML, and the Filter Coefficient XML files RTFLTxx.XML and RSFLTxx.XML must be in the same directory as the <HP_Config_XML_File>.

```
LTC_Cfg <HP_Config_Binary_File>
```

Lists the HP Configuration Binary file given by <HP_Config_Binary_File>

5.2.1 Usage for the LTC_Snsrs Tool

The LTC_Snsrs program converts a Sensor Definition XML File to the binary Sensor Definition file for uploading to the LAT onboard file system. LTC_Snsrs usages are:

```
LTC_Snsrs <Snsrs_Def_XML_File> <Snsrs_Def_File>
```

Converts file the XML file given by <Snsrs_Def_XML_File> to the binary file as given by <Snsrs_Def_File>.

```
LTC_Snsrs <Snsrs_Def_File>
```

Lists the Sensor Definition file given by <Snsrs_Def_File>

5.3 ITOS Command And Telemetry Files

An essential aspect of operating the LTC software is to have the correct ITOS files loaded onto the spacecraft GUI. The ITOS files define the LTC telecommand and telemetry formats for the spacecraft GUI. The ITOS files are built by the LCAT tool and are stored in the package "/cat" directory within the LTC CMX directory structure.

The telecommand and telemetry ITOS files used for LTC are:

- LTC_cmd_itos.dbx
- LTC_tlm_itos.dbx