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Gamma-ray Large Area Space Telescope (GLAST)

Large Area Telescope (LAT)

Calorimeter Flight Model

Comprehensive and Limited Functional Test Definition

DOCUMENT APPROVAL

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1 INTRODUCTION

1.1 PURPOSE

This document details the sequence and methods to be followed in performing comprehensive and limited functional tests of the Flight GLAST Calorimeter (CAL) Modules.

1.2 SCOPE

The Comprehensive and Limited Functional tests defined here shall be applied to all Flight CAL Modules during the Assembly and Test sequence at NRL. These functional tests shall also be executed during instrument Integration and Test at SLAC, as well as subsequent integration with the spacecraft, although they may be modified to better suite those environments.

1.3 APPLICABLE DOCUMENTS

The following documents are applicable to the extent specified within. Unless otherwise indicated, the latest issue in effect shall apply.

LAT-SS-00010	LAT Performance Specification – Level II (b) Specification
LAT-SS-00018	LAT CAL Subsystem Specification - Level III Specification
LAT-SS-00210	LAT CAL Subsystem Specification – Level IV Specification
LAT-TD-01502	LAT Calorimeter Subsystem Test Descriptions
LAT-MD-04187	CAL Electronic and Muon Calibration Definition

1.4 DEFINITIONS AND ACRONYMS

1.4.1 Acronyms

CAL	Calorimeter Subsystem of the LAT
CDE	Crystal Detector Element
GLAST	Gamma-Ray Large Area Space Telescope
LAT	Large Area Telescope
PDA	PhotoDiode Assembly
TBD	To Be Determined
TBR	To Be Resolved

1.4.2 Definitions

CAL Tower Module	The integrated Calorimeter Module, Tower Electronics Module, and Tower Power Supply
Analysis	A quantitative evaluation of a complete system and/or subsystems by review/analysis of collected data
Demonstrate	To prove or show, usually without measurements of instrumentation, that the project/product complies with requirements by observation of the results.
Test	A measurement to prove or show, usually with precision measurement or instrumentation, that the product complies with requirements.
Validate	To assure the requirement set is complete and consistent, and that each requirement is achievable.
Verify	To ensure that the selected solutions meet specified requirements and properly integrate with interfacing products

2 INTRODUCTION

2.1 TEST ENVIRONMENT

Functional testing of the CAL shall be performed within the LATTE test environment using test scripts and suites maintained under a configuration management system.

Data products and test reports shall be logged to disk in real time and later archived to a long-term storage medium. A description of the CAL data products, test scripts, and test suites can be found in LAT-TD-01502.

The LATTE Environmental Monitoring and Housekeeping shall be enabled at all times during the CAL functional testing. Environmental data products shall be logged to disk in real time and later archived to a long-term storage medium. The quantities thus monitored for each CAL Tower Module are the CAL analog and digital 3.3V voltage, the diode bias voltage and current, and one temperature on each of the four AFEE boards.

All functional testing shall be executed under approved and released work orders by trained personnel.

2.2 TEST PERSONNEL

Test personnel are defined below.

2.2.1 Test Director

The Test Director will have primary responsibility for directing functional test activities. The Test Director will be responsible for coordinating the inputs from the Test Conductor and Quality Assurance representatives, modifying the test script as circumstances dictate, and executing the Work Order.

2.2.2 Test Conductor

The Test Conductor will be responsible for monitoring the state of instrument electronics, executing specific functional test activities, and maintaining the test data logbook.

2.2.3 Analysis Support

The Analysis Support will be responsible for analyzing data collected during electrical functional testing and muon performance testing.

3 TEST DEFINITIONS

3.1 TEST SUITES

The functional tests are comprised of a series test scripts that form a suite executed under LATTE.

The CPT and LPT suites are outlined below as an ordered list of scripts. The motivation for each script is given in Sections 3.2 and 3.3 below, along with a description of the script algorithms and configurations. A detailed definition of each script is given in LAT-TD-01502.

3.1.1 Comprehensive Functional Performance Testing of AFEE and TEM Electronics

Comprehensive Functional Performance Testing shall provide verification of the full electrical function of the AFEE and those portions of the TEM electronics that interface with the CAL. The CPT shall be comprised of the following test procedures:

1. CALU_INIT: Initialize the Calorimeter.
2. CALF_EXR_P01: Exercise registers.
3. CALF_MARGIN: Test voltage and (optionally) frequency margins.
4. CALU_INIT: Initialize the Calorimeter.
5. CALF_PEDESTALS_CI: Compute pedestals.
6. CALU_INIT: Redefine pedestal file.
7. CALF_MU_OPTICAL: Check optical response with muons.
8. CALF_SHP_P01: Calibrate slow shaper and determine optimal charge-injection Tack time delay under Timed Readout.
9. CALF_SHP_P02: Calibrate slow shaper and determine optimal charge-injection Tack time delay under Self-Triggered Readout.
10. CALF_GAIN_P01: Calibrate electronic gains with charge injection.
11. CALU_COLLECT_CI_SINGLEX16: Determine front-end integral non-linearity and noise with charge injection.
12. CALU_COLLECT_CI: Determine front-end integral non-linearity and noise with charge injection.
13. CALF_ADC_P05: Evaluate front-end droop.
14. CALF_TRG_P01: Test CAL-LO and CAL-HI trigger enable/disable with charge injection.
15. CALF_TRG_P03: Characterize FLE and FHE DAC settings with charge injection.
16. CALF_TRG_P04: Characterize FLE and FHE trigger times.
17. CALF_SUPP_P01: Characterize LAC DAC settings with charge injection.
18. CALF_SUPP_P02: Determine lowest effective LAC DAC settings.
19. CALU_INIT: Redefine LAC table, setting LAC to its lowest effective setting.
20. CALF_RNG_P01: Characterize ULD DAC settings with charge injection.
21. CALF_DTM_P01: Estimate event deadtime with charge injection.
22. CALF_OVRLD_REC: Evaluate overload recovery with charge injection.

3.1.2 Limited Functional Performance Testing of AFEE and TEM

Limited Functional Performance Testing shall provide verification of selected elements of the electrical function of the AFEE and TEM electronics. The LPT shall be comprised of the following test procedures:

1. CALU_INIT: Initialize calorimeter.
2. CALF_EXR_P01: Exercise registers.

3. CALU_INIT: Initialize calorimeter.
4. CALT_PEDESTALS_CI: Compute pedestals.
5. CALU_INIT: Redefine pedestal file.
6. CALF_MU_OPTICAL: Check optical response with muons.

3.2 COMPREHENSIVE FUNCTIONAL PERFORMANCE TEST PROCEDURE

The CPT procedure shall include the following test steps. As defined herein, they are executed sequentially on a single CAL Tower Module.

In general, the CPT provides verification of functionality or performance and characterization of CAL parameters, rather than detailed calibrations of the controlling DACs. These simplified performance and characterization constants are then made available for trending analysis. The tests included in the CPT are sufficient to:

- verify full functionality of all CAL registers and proper communication with the TEM,
- measure pedestal centroids and widths,
- verify the stability of the optical bonds for all CDEs,
- measure the electronic gain, linearity, and integral non-linearity of each GCFE,
- characterize the low and high energy (FLE and FHE) discriminators,
- characterize the zero-suppression (LAC) threshold DAC,
- characterize the auto-ranging (ULD) discriminator DAC,
- estimate event deadtime,
- verify functionality of the overload recovery circuitry.

At all times during the CPT, Environmental Monitoring and Housekeeping shall be enabled.

1. CALU_INIT: Initialize the Calorimeter

The CAL initialization script shall be executed to ensure that the CAL is powered and begins the functional test in a defined configuration.

The default CAL test configuration is given in Table 1 below.

Parameter	Configuration
Diode bias	On, DAC set to 3072 (0xC00), equates to approx. 75 volts. 20 second wait is implemented to ensure bias has stabilized if setting change is needed
GCCC config	Configuration = 0x80090906 (per SLAC direction) Layer_mask_0/1 set based on schema FIFO_Status is cleared Latched Status is cleared Event Timeouts = 0 Trg_alignment = 0xa0f00 (per SLAC suggestion).
GCRC config	Delay_1 = nominal (30 clock tics with 20 MHz Clock) Delay_2 = nominal (60 clock tics with 20 MHz Clock) Delay_3 = nominal (144 clock tics with 20 MHz Clock)
GCFE config	FLE DAC = 127; FHE DAC = 127; LAC DAC = 127; ULD DAC = 127; REF_DAC = 127. Config_0 = 0

	Config_1 = 0
PDU config	CAL Analog voltage DAC = 2048 (3.3V) nominal CAL Digital voltage DAC = 2048 (3.3V) nominal
Miscellaneous	Clock Frequency (saved for time calculations)

Table 1: Default CAL configuration

2. CALF_EXR_P01: Exercise registers.

A set of patterns shall be written to and read from all CAL registers to verify that the registers are properly functioning. All bits of nearly all AFEE and GCCC read/write registers shall be exercised in all eight broadcast configurations. The GCCC configuration register requires the “Controller output enable bit” to be set. Certain fields in some registers are designed to read back fixed settings. This behavior is tested as part of the read back verification logic. In this test, read-only registers are queried only as needed to support read/write register testing.

The eight message broadcast configurations are composed of three register sets (GCCC, GCRC, and GCFE) in either of two states (broadcast on or off).

In each broadcast configuration, the bit patterns are chosen to test the functionality of reading to and writing from all bits. The patterns are all 0s, all Fs (hex), all As (hex), all 5s, walking 0s and 1s through the 16 bits of GCRC and GCFE registers, walking 0s and 1s through the 32 bits of GCCC registers, and a mailbox number (i.e. a unique, sequential number written to and read from each register or broadcast set of registers).

3. CALF_MARGIN: Test voltage and (optionally) frequency and duty-cycle margins.

The operations and communications margins shall be tested with the register exerciser at minimum and maximum voltage limits (i.e. the nominal 3.3V Vdd supply set to 3.0Vdc and 3.6Vdc). At the discretion of the Test Director or under WOA instructions, communications shall be tested at the minimum and maximum frequency limits (i.e. 14 MHz and 22 MHz, respectively). Again, at the discretion of the Test Director or under WOA instructions, communications shall be tested over a range of clock duty cycles.

The voltage, frequency, and duty cycle tests shall be sequential, with only a single limit tested at a time.

This test cannot be performed with a flight TEM/TPS and shall be excluded if the CPT is performed on a flight CAL with a flight TEM/TPS.

4. CALU_INIT: Initialize the Calorimeter.

The CAL initialization script shall be executed again to ensure that the CAL returns from the register exerciser in the proper command configuration. In addition, the most recent pedestal table and ADC-to-energy conversion table shall be loaded into the analysis environment to ensure that the analysis tools begin with the most up to date performance summary tables.

5. CALF_PEDESTALS_CI: Compute pedestals.

Pedestals for all energy ranges in all gain settings shall be computed by generating solicited triggers with zero charge injected. To avoid crosstalk or chatter, the FLE and FHE discriminators shall be set to their maximum values (i.e. 127). The pedestal is given by the centroid of a Gaussian fit to the observed ADC value from a large number (i.e. ~1000) of triggers at each gain setting. (Because the width of the pedestal distribution in the LEX1 and HEX1 ranges is ~1 bin, Gaussian fitting is ill-conditioned. Therefore, the pedestal centroid and width in these ranges shall be estimated by a simple mean and rms of the 5 ADC bins centered on the pedestal mode.)

Both the centroid and the width of the Gaussian shall be recorded for trending analysis. The pedestal value will be used in subsequent functional tests whenever conversion to energy units is required.

6. CALU_INIT: Redefine pedestal file.

The initialization script shall be executed again to load the new pedestal table generated in the previous step.

If so instructed by the controlling WOA, this redefinition and reinitialization step may be eliminated.

7. CALF_MU_OPTICAL: Check optical response with muons.

The stability of the optical bonds shall be monitored with sea-level muons. A collection of 10 minutes of muons is adequate to establish that the relative gain of the Plus and Minus PDAs (both LE and HE photodiodes) of each CDE has not changed more than 10%.

This test shall be performed in muon test gain (LE = 5; HE = 0). At this gain setting, the muon peak appears at ~5% of full scale in LEX8 and ~3% of full scale in HEX8. The data shall be read out in commanded-range (LEX8 first), 4-range mode to allow simultaneous verification of the LE and HE photodiodes. Zero-suppression shall be disabled to ensure that pedestals are registered in the dataset. The CAL shall self-trigger with CAL-LO enabled and CAL-HI disabled, with the FLE discriminators set to 8 MeV or below. The Tack delay shall be set at the "typical" optimal delay for CAL self-triggered readout, where "typical" shall be determined from the result of CALF_SHP_MUONS for the first few CAL Modules. Thus the actual Tack delay chosen may change from Module to Module early the CAL assembly and test process. Note that the diode ratios defined below should be essentially insensitive to modest shifts in the Tack delay from the truly optimal value, and are therefore relatively robust quantities to trend.

A sensitive test for changes in the PDA optical bond quality can be made from the ratio of LE diode signals from the Plus and Minus faces and the LE/HE ratio at each of the Plus and Minus faces. The diode ratios – LE(Plus)/LE(Minus), LE(Plus)/HE(Plus), and LE(Minus)/HE(Minus) – shall be calculated from the pedestal-subtracted ADC values in the LEX8 and HEX8 ranges. Pedestal values shall be taken from the recent calu_pedestals_ci test.

The three diode ratios for each CDE shall be recorded for trending analysis.

All energy ranges with no ADC values at least 10 pedestal-sigma above the pedestal shall be recorded as "dead" in the Dead Range table. If this test finds no such ranges in the Module under test, a null Dead Range table shall be created.

8. CALF_SHP_P01: Calibrate slow shaper and determine optimal charge-injection Tack time delay under Timed Readout.

The LE and HE slow shaping amplifier outputs shall be mapped and the optimal Tack time delay for charge-injection pulses under Timed Readout shall be determined.

At a single gain setting and charge-injection pulse amplitude, a large number of pulses (i.e. ~200) shall be generated at each of the 235 useful Tack Delay settings (settings less than 20 tics can cause register readout synchronization problems and shall therefore not be tested). The mean pulse height at each Tack Delay shall be calculated and stored. Because the peaking time of the LE and HE shapers is not identical, the optimal Tack Delay shall be defined to be the Tack Delay setting that gives the maximum pulse height averaged over all 192 LE shapers and 192 HE shapers in a Module (i.e. averaged over all 384 values).

This test shall be performed at nominal flight gain in both LE and HE ranges. To avoid any distortion of the shaper output caused by cross-talk from FLE or FHE discriminator firing, the FLE and FHE DACs shall be set at their maximum values (i.e. 127). To avoid potential distortions from small pulses or saturation of large pulses, the charge-injection DAC shall be set to give a pulse height in the middle of the LEX8 and HEX8 ranges.

The optimal Tack Delay under timed readout shall be recorded for trending analysis.

9. CALF_SHP_P02: Calibrate slow shaper and determine optimal charge-injection Tack time delay under Self-Triggered Readout.

The LE and HE slow shaping amplifier outputs shall be mapped and the optimal Tack time delay for charge-injection pulses under Self-Triggered Readout shall be determined. This optimal Tack Delay is expected to be shorter than the Tack Delay for Time Readout because of the finite fast shaping time and trigger message propagation time.

At a single gain setting and charge-injection pulse amplitude, a large number of pulses (i.e. ~200) shall be generated at each of the 235 possible Tack Delay settings (settings less than 20 tics can cause register readout synchronization problems and shall therefore not be tested). The mean pulse height at each Tack Delay shall be calculated and stored. Because the peaking time of the LE and HE shapers is not identical, the optimal Tack Delay shall be defined to be the Tack Delay setting that gives the maximum pulse height averaged over all 192 LE shapers and 192 HE shapers in a Module (i.e. averaged over all 384 values).

This test shall be performed at nominal flight gain in both LE and HE ranges. To ensure that the FLE and FHE discriminators fire at all Tack delay settings and thereby minimize any distortion of the shaper output, the FLE and FHE DACs shall be set to a low value (i.e. 10). To avoid potential distortions from small pulses or saturation of large pulses, the charge-injection DAC shall be set to give a pulse height in the middle of the LEX8 and HEX8 ranges.

The optimal self-triggered Tack Delay shall be recorded for trending analysis.

10. CALF_GAIN_P01: Calibrate electronic gains with charge injection.

The electronic gain of all gain settings for each energy range shall be calculated from charge-injection pulses that are below saturation in the highest gain setting. The mean pedestal-subtracted pulse height for a large number of pulses (i.e. ~200) shall be calculated in each gain setting.

The Tack delay shall be set to the optimal delay for Timed readout computed in this functional test suite. The pedestals subtracted shall be those calculated during this functional test suite.

The output of this test shall be a table expressing the gain of each setting relative to the nominal flight gain (i.e. LE = 5, HE = 13). The relative gain is defined as the ratio of the pedestal-subtracted pulse height in the current gain to that in the nominal flight gain.

The relative gain of the highest LE gain (i.e. LE = 0) and highest HE gain (i.e. HE = 8) shall be recorded for trending analysis. These gains are chosen because any drift from the nominal value would be most greatly amplified.

11. CALU_COLLECT_CI_SINGLEX16: Determine front-end integral non-linearity and noise with charge injection.

At the discretion of the Test Director, the integral linearity of the LEX8 energy range may be measured with charge-injection data. Charge shall be injected simultaneously into a limited number of GCFE chips to minimize the bias introduced into the linearity measurement by cross talk between neighboring GCFEs. Because the integral linearity is monitored by the following step in the functional test script, this no-crosstalk measurement is strictly optional.

This test shall be performed in the nominal flight gain (LE = 5; HE = 13). A modest number of pulses (~50) shall be generated at amplitudes spanning the LEX8 range in a pattern chosen to map the known regions of non-linearity. The default pattern sets the charge injection DAC from 0 to 512 in steps of 16, followed by 544 to 4095 in steps of 32. To maximize the information gathered for subsequent analysis, all four energy ranges shall be read out in auto-range order and zero-suppression shall be disabled.

A complete calibration of all four energy ranges is performed in the Electronic Calibration test (LAT-PS-04187).

The data shall be analyzed to determine the maximum integral non-linearity and noise in each energy range. A linear least-squares fit shall be performed to the mean pedestal-subtracted ADC value at each pulse amplitude, and the maximum deviation from the linear model shall be determined and expressed as a fraction of the maximum unsaturated ADC value. The rms width of the ADC value at each pulse amplitude shall be calculated; this is a measure of the noise in each channel as a function of pulse amplitude (although it contains a contribution from the charge-injection system).

The slope of the linear fit, the maximum deviation from the linear fit, the mean noise in each range, and the maximum noise (i.e. maximum rms width) shall be recorded for trending analysis. Trending data from calu_collect_ci_singlex16 shall be marked as having minimal crosstalk.

12. CALU_COLLECT_CI: Determine front-end integral non-linearity and noise with charge injection.

The integral linearity of all energy ranges shall be measured with charge-injection data. To speed the test, charge shall be injected simultaneously into all GCFE chips, but this injection is known to introduce a bias in the observed ADC values from cross talk between neighboring GCFEs. Data from this test shall therefore never be used to generate a calibration of the linearity; instead the best measurement of the linearity shall be made in the Electronic Calibration suite (LAT-PS-04187).

This test shall be performed in the nominal flight gain (LE = 5; HE = 13). A large number of pulses (~200) shall be generated at amplitudes spanning the full range of the charge-injection DAC (i.e. 0 to 4095) at constant step size (i.e. 32). To maximize the information gathered for subsequent analysis, all four energy ranges shall be read out in auto-range order and zero-suppression shall be disabled.

The charge injection data collected in CALU_COLLECT_CI shall be analyzed to determine the maximum integral non-linearity and noise in each energy range. A linear least-squares fit shall be performed to the mean pedestal-subtracted ADC value at each pulse amplitude, and the maximum deviation from the linear model shall be determined and expressed as a fraction of the maximum unsaturated ADC value. The rms width of the ADC value at each pulse amplitude shall be calculated; this is a measure of the noise in each channel as a function of pulse amplitude (although it contains a contribution from the charge-injection system).

The slope of the linear fit, the maximum deviation from the linear fit, the mean noise in each range, and the maximum noise (i.e. maximum rms width) shall be recorded for trending analysis. Trending data from CALU_COLLECT_CI shall be marked as being biased by crosstalk.

13. CALF_ADC_P05: Evaluate droop.

The amount of GCFE track-and-hold droop between the first and last readout shall be measured with charge injection pulses.

This test shall be performed in the nominal flight gain (LE = 5; HE = 13). A large number of pulses (~200) shall be generated at amplitudes spanning the full range of the charge-injection DAC (i.e. 0 to 4095) at constant, large step size (i.e. 128). All four energy ranges shall be read out in commanded order and zero-suppression shall be disabled. The test shall be executed with each of the four ranges commanded to be read out first.

The mean ADC value for each charge injection setting and readout order shall be calculated. The droop is then defined to be the ratio of the mean ADC value at each readout order to the mean ADC value when that energy range is read out first.

14. CALF_TRG_P01: Test CAL-LO and CAL-HI trigger enable/disable with charge injection.

The functionality of the FLE and FHE trigger primitives of each GCFE shall be tested with charge injection pulses. For each GCFE and trigger source (FLE/CAL-LO and FHE/CAL-HI) in sequence, the discriminator shall be enabled, charge shall be injected, and the LRS counters inspected to determine if the CAL-LO or CAL-HI trigger has been processed.

This test shall be performed in the nominal flight gain (LE = 5; HE = 13). LRS data collection shall be enabled.

15. CALF_TRG_P03: Characterize FLE and FHE DAC settings with charge injection.

The pulse amplitudes at which the FLE and FHE discriminators fire shall be characterized with charge injection. This characterization is distinct from a calibration in that only a small number of DAC settings are examined.

This test shall be performed in the nominal flight gain (LE = 5; HE = 13). For each column of GCFEs sequentially, the FLE DAC shall be set to one of ten levels spanning the fine and coarse ranges (i.e. 0, 4, 21, 42, 63, 64, 68, 85, 106, and 127), and the charge-injection DAC shall be ramped upward one step at a time, with a small number of pulses (~20) generated at each amplitude. The trigger diagnostic data shall be inspected to determine if the FLE discriminators have fired. If the FLE fires for >90% of the pulses, the corresponding mean ADC value shall be recorded. This process shall then be repeated for the FHE DAC.

The output of this process is a pair of tables of correspondence between FLE/FHE DAC setting and ADC bin number in the nominal flight gain ("fle2adc" and "fhe2adc").

Note that this characterization is not a precise calibration of the discriminator thresholds in energy units because the charge injection pulse shape is not identical to the scintillation pulse shape; the ratio of fast-shaped to slow-shaped signals is therefore different for charge injection pulses than for scintillation pulses.

A complete characterization of the FLE and FHE discriminator thresholds with charge injection shall be performed in the Electronic Calibration test (LAT-PS-04187).

The slope (i.e. change in ADC bin per change in DAC setting) of the coarse range of the FLE and FHE DACs shall be recorded for trending analysis.

16. CALF_TRG_P04: Characterize FLE and FHE trigger times.

The time delay between pulse injection and the appearance of the FLE trigger primitive in the diagnostic data shall be characterized with charge injection.

This test shall be performed in the nominal flight gain (LE = 5; HE = 13). Data shall be read in auto-range, one-range, zero-suppressed mode. For each column of GCFEs sequentially, the FLE DAC shall be set to an intermediate value, the charge-injection DAC to a high value (known to be above the FLE threshold), and a small number of pulses (~20) generated at each of the 256 Tack delay values. The trigger diagnostic data shall be inspected to determine if the FLE discriminators have fired. The minimum Tack delay for which the FLE fires for >90% of the pulses shall be recorded as the FLE trigger time.

This process shall then be repeated for the FHE DAC.

17. CALF_SUPP_P01: Characterize LAC DAC settings with charge injection.

The pulse amplitudes at which the Log-Accept discriminators fire shall be characterized with charge injection. This is not a calibration because only a subset of the LAC DAC settings is examined.

This test shall be performed in the nominal flight gain (LE = 5; HE = 13). Because the LAC functions as the logical OR of the discriminators at both end faces of a CDE, the faces must be tested separately. Thus, all Plus-face discriminators shall be tested together, then all Minus-face discriminators. All Plus-face discriminators shall be tested simultaneously. On the face not under test, all LAC DACs shall be set to the maximum value (i.e. 127). The LAC DAC shall be set one of ten levels spanning the fine and coarse ranges (i.e. 0, 4, 21, 42, 63, 64, 68, 85, 106, and 127), and the charge-injection DAC shall be ramped upward one step at a time, with a small number of pulses (~20) generated at each amplitude, until all LACs have fired. The LEX8 event data for each CDE shall be inspected to determine if the LAC discriminator has fired. For each channel (FE), the average ADC reading obtained from the first charge injection setting that causes data from that channel to be present in the event readouts for 90% of the samples shall be saved. For each GCFE, the mean ADC value for the lowest charge-injection setting that causes that GCFE to be present in the event readouts for >90% of the samples shall be recorded.

This process shall then be repeated with the Plus and Minus LAC DACs incremented together to test the functionality of the OR of the CDE faces, i.e. the LAC threshold should be equal to the lesser of the Plus and Minus face thresholds.

The output of this process is a table of correspondence between the LAC DAC setting and LEX8 ADC bin number in the nominal flight gain (“lac2adc”).

The slope (i.e. change in ADC bin per change in DAC setting) of the coarse range of the LAC DAC shall be recorded for trending analysis.

18. CALF_SUPP_P02: Determine lowest-effective LAC DAC settings.

The lowest LAC DAC setting for which pedestals are excluded shall be determined for each channel. This setting is therefore the lowest for which the LAC functions effectively as zero suppression.

This test shall be performed in the nominal flight gain (LE = 5; HE = 13). For each LAC DAC setting from 0 to 50, a small number (~50) of solicited triggers shall be generated with zero charge injection. (The maximum LAC DAC setting of 50 was chosen because it is known to correspond to ADC bins somewhat above the maximum pedestal.) The event data shall then be inspected to determine the fraction of samples for which each channel is present in the “zero-suppressed” stream. For each GCFE, the lowest LAC DAC setting that causes the channel to be excluded in >90% of the samples shall be recorded as the lowest effective setting.

The setting thus determined may then be compared to the setting that corresponds estimated from the pedestal width, namely the lac2dac table entry closest to the ADC value that corresponds to 3 Gaussian sigmas above the pedestal centroid. The lowest effective LAC DAC setting for all channels shall be below 5 MeV.

All channels with a lowest-effective LAC DAC setting above 5 MeV shall be recorded as “noisy” in the Noisy Channel table. If this test finds no such channels in the Module under test, a null Noisy Channel table shall be created.

19. CALU_INIT: Redefine lac2dac.

The initialization script shall be executed again, in this case to load the new LAC setting (“lac2dac”) table generated in the previous step.

If so instructed by the controlling WOA, this redefinition and reinitialization step may be eliminated.

20. CALF_RNG_P01: Characterize ULD DAC settings with charge injection.

The correspondence between the Upper Level Discriminator (ULD) DAC setting and the ADC value at which the range selection is made shall be characterized with charge injection. This is a characterization rather than a calibration, because only a subset of the ULD DAC settings is examined.

This test shall be performed in the nominal flight gain (LE = 5; HE = 13) with the data read out in one-range, auto-range order. The ULD DAC shall be set one of ten levels spanning the fine and coarse ranges (i.e. 0, 4, 21, 42, 63, 64, 68, 85, 106, and 127), and the charge-injection DAC shall be ramped upward one step at a time, with a small number of pulses (~20) generated at each amplitude. The ADC values at which LEX8 transitions to LEX1, LEX1 transitions to HEX8, and HEX8 transitions to HEX1 shall be recorded at each ULD DAC setting.

The complete calibration of ULD DAC settings shall be performed as part of the Electronic Calibration suite (LAT-PS-04187).

The slope (i.e. change in ADC bin per change in DAC setting) of the coarse range of the ULD DAC shall be recorded for trending analysis.

21. CALF_DEADTIME: Estimate event deadtime.

An estimate of the event deadtime shall be calculated using charge injection.

This test shall be performed in the nominal flight gain setting (LE = 5; HE = 13). The LAC threshold shall be set at its lowest-effective setting determined with CALF_SUPP_P02, and zero suppression shall be enabled. Data shall be read out in one-range, auto-range mode to minimize the readout time to the TEM. The GTIC deadtime LRS counter mask shall be set to count CAL deadtime only. A large number (i.e. ~1000) of solicited triggers with the charge injected into a single GCFE shall be generated. The total number of solicited triggers, the total number of events read out, and the total LRS dead time counter accumulation from the TEM shall be logged.

The average dead time is then given by the ratio of the total LRS data time to the total number of events read out.

The average dead time shall be recorded for trending analysis.

22. CALF_OVRLD_REC: Verify functionality of overload recovery using charge injection.

The operation of the active overload recovery shall be verified using charge injection pulses. Data from solicited triggers with null charge injection that follow immediately after solicited triggers with maximal injected charge may be inspected for evidence of incomplete baseline restoration.

This test shall be performed in the highest gain setting (LE = 0; HE = 0). The FLE and FHE DACs shall be set to their maximum values (127) to avoid crosstalk or chatter. The LAC threshold shall be set at its lowest-effective setting determined with CALF_SUPP_P02 (adjusted for gain using the *relgain* table), and zero suppression shall be enabled. Data shall be read out in one-range, auto-range mode to minimize the readout time to the TEM. A single solicited trigger with the charge injection DAC set to its maximum value shall be generated into all GCFEs, followed by five solicited triggers with charge injection DAC = 0. This sequence of 1 maximal pulse followed by 5 minimal pulses shall be repeated 100 times, for a total of 600 solicited triggers. Finally, 500 additional pulses with null charge injection shall be generated as a reference for comparison.

The event multiplicity (i.e. the number of channels present in the event data) shall be histogrammed for the 100 events at each of the five minimal-pulse sample steps and the 500 events in the null charge reference set. The mean event multiplicity for each of the six histograms shall be calculated and compared.

The CAL readout is required to recover from a ×1000 overload within 100 μsec. Note that the test given here is inadequate to verify compliance of the overload recovery circuitry with its requirements for at least two reasons: first, the charge injection system cannot deliver a ×1000 overload pulse, and second, there is no guarantee that the solicited trigger sample occurs at the specified interval.

3.3 LIMITED FUNCTIONAL TEST PROCEDURE

The LPT suite shall include the following test steps. As defined herein, they are executed sequentially on a single CAL Tower Module. The tests included in the LPT are a subset of those in the CPT. In addition, some of the tests themselves are abbreviated forms of the test in the CPT.

The tests included in the LPT are sufficient to verify the following:

- Proper communication between TEM and CAL at nominal voltage and frequency.
- Functionality of all bits of all CAL registers.
- Stability of pedestals and pedestal noise in all four ranges of each GCFE.
- Stability of the optical contact of all LE and HE photodiodes.

At all times during the LPT, Environmental Monitoring and Housekeeping shall be enabled.

1. CALU_INIT: Initialize the Calorimeter

The CAL initialization script shall be executed to ensure that the CAL is powered and begins the functional test in a defined configuration.

The default CAL test configuration is given in Table 1 above (i.e. identically as in CPT).

2. CALF_EXR_P01: Exercise registers.

A set of patterns shall be written to and read from all CAL registers to verify that the registers are properly functioning. All bits of all registers shall be exercised in all eight broadcast configurations; however, fewer bit patterns shall be tested with this abbreviated test.

The eight message broadcast configurations are composed of three register sets (GCCC, GCRC, and GCFE) in either of two states (broadcast on or off).

In each broadcast configuration, the bit patterns are chosen to test the functionality of reading to and writing from all bits. The patterns are all 0s, all Fs (hex), all As (hex), all 5s, and a mailbox number (i.e. a unique, sequential number written to and read from each register or broadcast set of registers).

3. CALU_INIT: Initialize the Calorimeter.

The CAL initialization script shall be executed again to ensure that the CAL returns from the register exerciser in the proper command configuration. In addition, the most recent pedestal table and ADC to energy conversion table shall be loaded into the analysis environment to ensure that the analysis tools begin with the most up to date performance summary tables.

4. CALF_PEDESTALS_CI: Compute pedestals.

Pedestals for all energy ranges in all gain settings shall be computed by generating solicited triggers with zero charge injected. To avoid crosstalk or chatter, the FLE and FHE discriminators shall be set to their maximum values (i.e. 127). The pedestal is given by the centroid of a Gaussian fit to the observed ADC value from a large number (i.e. ~1000) of triggers at each gain setting. (Because the width of the pedestal distribution in the LEX1 and HEX1 ranges is ~1 bin, Gaussian fitting is ill-conditioned. Therefore, the pedestal centroid and width in these ranges shall be estimated by a simple mean and rms of the 5 ADC bins centered on the pedestal mode.)

Both the centroid and the width of the Gaussian shall be recorded for trending analysis. The pedestal value will be used in subsequent functional tests whenever conversion to energy units is required.

5. CALU_INIT: Redefine pedestal file.

The initialization script shall be executed again to load the new pedestal table generated in the previous step.

If so instructed by the controlling WOA, this redefinition and reinitialization step may be eliminated.

6. CALF_MU_OPTICAL: Check optical response with muons.

The stability of the optical bonds shall be monitored with sea-level muons. A collection of 10 minutes of muons is adequate to establish that the relative gain of the Plus and Minus PDAs (both LE and HE photodiodes) of each CDE has not changed more than 10% (TBR).

This test shall be performed in muon test gain (LE = 5; HE = 0). At this gain setting, the muon peak appears at ~5% of full scale in LEX8 and ~3% of full scale in HEX8. The data shall be read out in commanded-range (LEX8 first), 4-range mode to allow simultaneous verification of the LE and HE photodiodes. Zero-suppression shall be disabled to ensure that pedestals are registered in the dataset. The CAL shall self-trigger with CAL-LO enabled and CAL-HI disabled, with the FLE discriminators set to 8 MeV or below. The Tack delay shall be set at the optimal delay for CAL self-triggered readout, as determined elsewhere by CALF_SHP_MUONS.

A sensitive test for changes in the PDA optical bond quality can be made from the ratio of LE diode signals from the Plus and Minus faces and the LE/HE ratio at each of the Plus and Minus faces. The diode ratios – LE(Plus)/LE(Minus), LE(Plus)/HE(Plus), and LE(Minus)/HE(Minus) – shall be calculated from the pedestal-subtracted ADC values in the LEX8 and HEX8 ranges. Proper analysis of the muon data requires that the most recent pedestals be used.

The three diode ratios for each CDE shall be recorded for trending analysis.