LANDSAT DATA CONTINUITY MISSION

Thermal Infrared Sensor Special Calibration Test Requirements

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Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and Space Administration

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CM Foreword

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Questions or comments concerning this document should be addressed to:

LDCM Configuration Management Office
Mail Stop 427
Goddard Space Flight Center
Greenbelt, Maryland 20771

Signature Page

Prepared by:

Concurrence on File	*11/19/12*	*Concurrence on File*	*11/19/12*
Brian L. Markham LDCM Calibration/Validation Scientist NASA/GSFC – Code 614.4	Date	James C. Storey USGS LDCM Systems Engineer USGS/EROS – SGT	Date

Reviewed by:

Concurrence on File	*11/15/12*	*Concurrence on File*	*11/27/12*
John Dwyer USGS LDCM Science USGS/EROS	Date	Philip W. Dabney LDCM TIRS Instrument Scientist NASA/GSFC – Code 694	Date
Concurrence on File	*12/06/12*	*Concurrence on File*	*12/03/12*
Evan H. Webb LDCM Mission Systems Manager NASA/GSFC – Code 599	Date	Edward G. Grems Systems Engineer NASA/GSFC 427 – a.i. solutions	Date
Concurrence on File	*11/15/12*	*Concurrence on File*	*12/06/12*
Jeanine Murphy-Morris LDCM Observatory Manager NASA/GSFC – Code 427	Date	Del Jenstrom LDCM Deputy Project Manager NASA/GSFC – Code 427	Date

Approved by:

Signature on File (D. Jenstrom for)	*12/06/12*
Kenneth Schwer LDCM Project Manager NASA/GSFC – Code 427	Date

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1 Introduction

1.1 Purpose

The LDCM program elements are dependent on the pre-flight and on-orbit commissioning phase characterization and calibration of the imaging sensor and related subsystems, and, in particular, on the data sets and written reports from those tests. It is through the preflight test reports that the required elements of the Image Assessment System will be identified. In addition, the algorithms and input parameters to process the image data will be developed using these preflight data sets.

The purposes of the pre-flight and commissioning phase test requirements are to:

- verify that the instrument's operation conforms to specifications;
- establish the instrument's as-built performance;
- test for abnormalities in the sensor's response;
- provide an at-launch estimate of the sensor's radiometric calibration;
- provide characterization data sets that are otherwise unobtainable in flight or on the ground (such as spectral band characteristics, PSF parameters, and solar diffuser reflectance); and
- determine the instrument's radiometric stability.

The TIRS instrument Provider has the responsibility for providing an instrument(s) capable of providing well calibrated, well characterized and specification compliant data, to ensure Landsat data continuity. The Government has the responsibility for independently assuring that the delivered instrument will be specification compliant and sufficiently well calibrated and characterized to fulfill the Mission objectives. The following Special Calibration Test Requirements (SCTRs) are an essential component of that independent assurance program

1.2 Definitions

The observatory elements identified in Figure 1-1 and defined below are provided for clarification of terms used in the SCTR and are not intended to dictate a design implementation.

Refer to the LDCM Acronym List and Lexicon for more Definitions.

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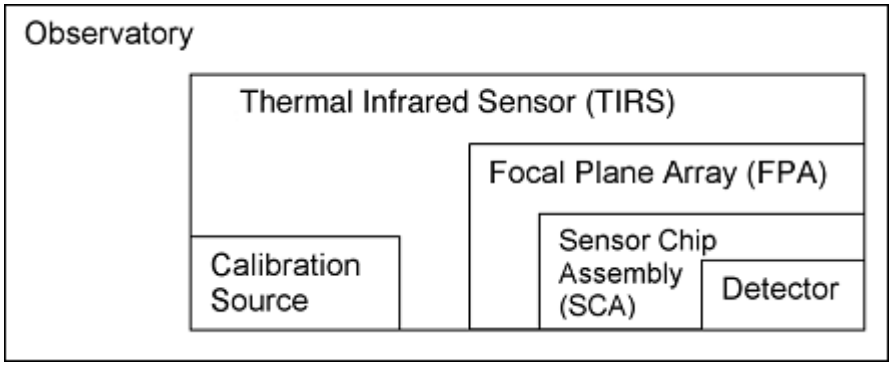

Figure 1 - 1 Relationship of Elements in the SCTR

Thermal Infrared Sensor (TIRS) - The LDCM sensor payload designed to collect data for the LDCM thermal bands 10 (10.3-11.3 µm) and 11 (11.5-12.5 µm)

Sensor - The integrated instrument comprising optics, spectral bandpass filters, sensing elements, electronics, calibration source(s), and associated mechanisms and structural elements.

Focal Plane Array (FPA) - The detectors and associated electronics assembled with the spectral bandpass filters. A focal plane array comprises one or more sensor chip assemblies illuminated by a common optical path, and the associated electronics.

Calibration Source - A component of the sensor that provides controlled and/or measured reference radiance input to the TIRS sensing elements for purposes of calibration.

Simulated On-Orbit Operating Conditions - Temperature and pressure environmental conditions similar to those experienced on-orbit, i.e., thermal vacuum.

Vacuum - Atmospheric pressure of 10^{-5} torr or less as defined in the LDCM Environmental Verification Requirements (LEVR).

Operational Temperature Range - The range of temperatures over which an LDCM subsystem or component is designed to operate while meeting all specifications.

Determine - Use one or more measurements and associated analyses to estimate the value for a particular system parameter or performance characteristic.

1.3 Scope

The following test requirements do not constitute a complete set of tests. The Provider is responsible for verification and validation of all TIRS instrument requirements. The tests described herein are included as part of the Provider's overall validation program as required in the Calibration/Validation Plan (CV-1).

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2 General Test Requirements

SCT-33 Sampling methods and their statistical validity shall be described in the calibration/validation plan (DRL CV-1).

SCT-34 The sampling of the instrument and focal plane temperatures to be used for the characterizations shall be described in the calibration/validation plan (DRL CV-1).

SCT-35 The Provider shall calibrate radiance calibration sources to National Institute of Standards and Technology (NIST) standards for radiometric calibrations.

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3 Thermal Band Pre-Flight Test Requirements

3.1 Spectral Test Requirements

SCT-38 The Provider shall measure the spectral transmission of the spectral bandpass filters per the parameters in the table below.

SCT-39 The Provider shall measure the relative spectral radiance response of a sample of detectors per the parameters in the table below.

SCT-40 The Provider shall measure the spectral transmission or reflectance of the optical elements of the instrument telescope per the parameters in the table below.

SCT-41 The Provider shall measure the in-band relative spectral radiance response of the instrument per the parameters in the table below.

SCT-42 The Provider shall determine the out-of-band relative spectral radiance response of the instrument per the parameters in table below.

SCT-43 The Provider shall characterize the stability of the in-band spectral transmission of the spectral band bandpass filters under vacuum condition per the parameters in table below.

SCT-44 The Provider shall measure the spectral transmission of any optical windows in the optical path of the radiometric or spectral calibrations per the parameters in the table below.

SCT-45 The spectral transmission or reflectance of the assembled telescope shall be characterized per parameters in the table below.

Rationale: These spectral calibration tests are used to determine compliance with spectral requirements (section 5.4.1 of TIRS requirements document [TIRS-RD]). Also, these measurements are required in order to perform the radiometric calibration of the instrument and provide the user community the fundamental spectral characteristics of the data. The component (SCT-38 - SCT-40) and assembly (SCT-45) level measurements will be used to predict the system level response and assure the final system will likely meet relative spectral response requirements; however, measuring the response on the assembled instrument in as close to operational conditions as possible is required for an adequate characterization (SCT-41). The spectral uniformity requirement, in particular, requires characterization of the variation in the system level responses (section 5.4.3 and 5.6.2.3 of TIRS-RD). It is difficult to obtain sufficient energy to measure the out-of-band response at the integrated instrument level, so measurements at the detector mated to filter assembly level are allowed for this characterization (SCT-42). Test SCT-43 is intended to verify that the TIRS filters will likely meet the spectral stability requirement for TIRS (section 5.4.4 of TIRS-RD). (The spectral and radiometric characterizations of the integrated instrument may be done through optical windows; characterizations of the spectral transmission of these optical windows are required, if this is the case.)

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Table 3 - 1 Thermal Band Spectral Test Minimum Acceptable Requirements

Test	Assembly Level	Unit	Measurement Conditions	Spatial Samples	Wavelength Range	Wavelength Sampling, Wavelength Resolution (FWHM)	Sensitivity
SCT-38	Component	Filter	Operational angular and temperature conditions (cover range of angles and temperatures expected)	5 per flight filter wafer	0.3-30 µm or where detector response and optics transmission / reflectance exceed 0.001 of peak.	In-band[1]: 50 nm Out-of-band[1]: 500 nm	0.005 of peak (1σ)) in band; SNR>10 out of band
SCT-39	Component	Detector	Operational angular and temperature conditions (cover range of angles and temperatures expected)	1% of detectors uniformly distributed across each flight SCA per band	0.3-30 µm or where detector response exceeds 0.001 of peak.	100 nm [1]	0.005 of peak (1σ from 10-13 µm; SNR>10 elsewhere

[1] Measurements shall be compared to a model if available. If the relative difference between model and measurement is > 10%, or if the absolute difference between model and measurement is 0.01, whichever is greater, the spectral sampling resolution shall be decreased by factors of 2 until sufficient agreement is obtained.

Test	Assembly Level	Unit	Measurement Conditions	Spatial Samples	Wavelength Range	Wavelength Sampling, Wavelength Resolution (FWHM)	Sensitivity

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SCT-40	Component	Optical elements or witness samples	Operational angular and temperature conditions (cover range of angles and temperatures expected)	3 samples of each optical surface	0.3-30 µm or where predicted optics transmittance/reflectance exceeds 0.001 of peak.	100 nm [1]	0.005 of peak (1σ) from 10-13 µm; SNR>10 elsewhere
SCT-41	Integrated Instrument		Vacuum; operational focal plane temperature	Same detectors as in "3.1.2", plus 10% of detectors uniformly distributed across focal plane	Between 0.005 response points	100 nm	0.005 (1 σ)
SCT-42	Assembly or above	Mated Filter/ Detector Assembly Level or above;	Operational angular and temperature conditions with adjacent bands illuminated	Same detectors as in "SCT-39"	0.3-30 µm or where detector response and optics transmission/ reflectance exceeds 0.001 of peak.	500 nm	SNR>10
SCT-43	Component	Filter witness samples	In vacuum after 1, 3, 5 and 7 days of vacuum exposure	1 filter per band; 3 spots per filter	2- 20 µm or to 0.001 of peak response of detector	In-band: 50 nm Out-of-band: 500 nm	0.001 (1s)

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SCT-44	Calibration Equipment	Optical Window (s)	Ambient Conditions	5 spots	2-20 µm or where detector response and optics transmission/ reflectance exceed 0.001 of peak.	In-band1: 50 nm Out-of-band1: 500 nm	
SCT-45	Assembly	Telescope	As required	Adequate to characterize changes in transmission across the Focal Plane with a minimum of one sample per SCA location	10-13 µm	50 nm	

3.2 Spatial Test Requirements

SCT-132 The Provider shall characterize the spatial edge response based on measurements at the integrated instrument level, pre- and post-vibration testing, and under simulated on-orbit operating conditions across the entire FOV in all bands.

Rationale: These measurements will be used to verify the TIRS Edge Response requirements (Section 5.5.2 of the TIRS-RD). Edge response may be a function of location with the focal plane, hence the requirement to characterize across the entire FOV.

Measurement conditions:

One measurement at each cross-track edge of each SCA and one at the center of the cross-track FOV

0.1 IFOV increments from ± 2 IFOV from center of detector in both along-track and across-track directions

0.5 IFOV increments from 2 to 10 IFOV from center of detector in both along track and across-track directions

At the nominal and the high and low acceptance temperatures

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Data will be collected from both bands during each bands testing, if the two bands are tested separately.

Note: Test data collection must be performed with TDI turned off, in a diagnostic mode if necessary, to allow the edge response to be oversampled. The effect of TDI on edge response performance will be evaluated by analysis.

SCT-141 * The Provider shall measure the optical power and distortion of any optical window used in the calibration path under expected thermal vacuum operating conditions.

Rationale: Spatial measurements performed through any window will be affected by the window's optical properties.

* Contingent on the existence of optical window(s) in the optical path of any geometric calibration

SCT-143 The Provider shall characterize the stray light rejection and internal light scattering of the instrument based on measurements at the component level or above and analysis.

SCT-144 The stray light model shall be developed using a Government-approved non-sequential ray trace method, e.g. ASAP, APART, GUERAP, or Trace Pro.

SCT-145 The stray light model shall encompass the entire optical system, including baffles and the focal plane, detectors and mounting devices and all portions of the satellite bus and other payloads that may reflect or emit light into the sensor.

Rationale: These measurements and analysis will be used to verify section 5.5.4 of the TIRS-RD and sections of the IRD.

SCT-147 The Provider shall demonstrate that the on-board blackbody measurements on orbit are not contaminated by radiation from the Earth or the atmosphere.

Rationale: This characterization will allow the on-board blackbodies to be used as an absolute calibration source: the observatory, the instrument itself and the Earth may all contribute stray light to the on-board calibrator.

SCT-149 The Provider shall verify the ghosting requirements (section 5.5.5 of the TIRS-RD) are met by using the stray light model in SCT-143.

SCT-150 The Provider shall verify the ghosting requirements (section 5.5.5 of the TIRS-RD) are met by test at the integrated instrument level using a broadband far-field illuminated object.

SCT-151 The object shall be scanned across the full FOV of the telescope.

SCT-152 The test object shall be at least 0.2° x 0.2° with the data combined to demonstrate performance when imaging a 1.5°x 1.5° object.

3.3 Radiometric Test Requirements

SCT-154 The Provider shall radiometrically calibrate all detectors at the integrated instrument level per the parameters in the table below.

SCT-155 The Provider shall characterize the radiometric sensitivity model for the instrument thermal environment, i.e., contributions of instrument emitted radiance to the instrument response per the parameters in the table below.

SCT-156 The Provider shall collect calibration data sets and characterization data to demonstrate that the calibrated data will meet the absolute radiometric accuracy, pixel-to-pixel uniformity and radiometric stability requirements on orbit per the parameters in the table below.

SCT-157 The Provider shall determine the mathematical equation(s) to convert the instrument output in DN to input radiance per the parameters in the table below.

SCT-158 The Provider shall estimate the time required to recover from various on-orbit operations that change the instrument environment, e.g., off-nadir viewing, lunar viewing, delta inclination maneuvers, etc., and reach radiometric performance requirements.

Rationale: These tests (SCT-154 - SCT-157) provide the basic radiance calibration of the instrument. The characterization of the mathematical form of the radiance calibration (e.g., linear) may be more accurately performed before integration of the focal plane into the instrument, whereas the final pre-launch calibration (SCT-154) is performed on the integrated instrument. The instrument contributes a signal to the detectors depending on its internal temperatures; the characterization of this contribution is performed in SCT-155. Timing estimates for the nominal performance recovery period following simulated thermal drifts that on-orbit will be induced by the following: FPA outgassing, off-nadir viewing, and any other operational planned maneuvers or conditions that impact either the instrument thermal control, the FPA thermal control, or the Blackbody thermal control. Verification that the instrument, the radiance calibration and the radiance calibration algorithm perform to requirements for accuracy, stability and pixel-to-pixel uniformity (in part) (sections 5.6.1, 5.6.4, 5.6.2.3) occur in SCT-156.

SCT-160 The Provider shall characterize the spatial and angular distribution of the temperature and emissivity of the on-board blackbody(s) at all operational set points. This characterization shall be performed at least twice.

Rationale: The on-board blackbodies provide the emitted radiance-based calibration of the instrument (section 5.8 of TIRS-RD). We need to know the absolute radiance and spatial profile at the front objective of the TIRS imaging telescope using only the on-board telemetry. Radiometric calibration is dependent on the repeatability of the Blackbody emitted radiance during on-board calibrations - this test characterizes that stability and allows validation of the requirements in item 5.8.3 from the TIRS-RD. The need for at least two measurements is to demonstrate reproducibility. Exact timing is not critical.

SCT-162 The Provider shall characterize the temperature and radiance stability of the blackbody(s) over a minimum of 40 minutes or the planned time between

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instrument calibrations, whichever is longer, per the parameters in the table below.

SCT-163 The Provider shall characterize the noise equivalent radiance errors (NEΔL) (section 5.6.2.1 of TIRS-RD) of all detectors with integrated instrument level measurements under simulated on-orbit operating conditions per the parameters in the table below.

SCT-164 The Provider shall characterize the stability of the instrument response under simulated on-orbit operating conditions per the parameters in the table below.

SCT-165 The Provider shall characterize the detector bias and gain stability across expected on-orbit on-off cycling of the instrument per the parameters in the table below over at least three simulated orbits.

SCT-166 The Provider shall characterize 1/f noise parameters per the parameters in the table below.

SCT-167 The Provider shall characterize the coherent noise (section 5.6.2.4 of TIRS-RD) of the instrument near the Ltypical illumination level per the parameters in the table below.

SCT-168 The Provider shall verify the bright target recovery and detector-to-detector crosstalk requirements of the instrument (section 5.6.5.1 of TIRS-RD) per the parameters in the table below.

SCT-169 The Provider shall provide and maintain a detector operability status list that includes dead, inoperable, and out-of-spec detectors for each band (section 5.6.6 of TIRS-RD).

Table 3 - 2 Thermal Radiometric Test Minimum Acceptable Requirements

Test	Assembly Level	Measurement Ambient Atmospheric Conditions	Measurement Temperature Conditions	Radiance Levels		Comments

SCT -154, SCT -163, SCT -167	Integrated Instrument	Thermal Vacuum (nominal temperature)	Nominal controlled operational focal plane and instrument/ telescope temperature, (for SCT-154 - at each operational focal plane temperature set point and additional samples @+/- 3sigma of the control levels at each set point)	10 levels between an apparent blackbody temperature of 240K and 360K (only 5 levels required for SCT-167)		Internal Blackbodies to be operated to verify and update their characterizatio n during these tests
SCT -155	Integrated Instrument	Thermal Vacuum (high and low temperature plateaus)	Nominal operational focal plane temperature	External Blackbody at an apparent blackbody temperature of 240K		Each instrument control temperature to be separately varied during this test: blackbody, optics, housing, etc.
SCT -156, SCT -162, SCT -164, SCT -165	Integrated Instrument	Thermal Vacuum	Nominal operational focal plane temperature	Simulated orbits with external calibration source. Repeated at least once.		Internal Blackbodies to be operated during these tests; FPA resets per on-orbit operation

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SCT -157, SCT -168	Focal plane level or above	No requirement	Nominal operational focal plane temperature	20 levels between 240K and 360K for SCT-157		
SCT -158	Integrated Instrument	Thermal Vacuum	Each instrument temperature at nominal value (BB's, housing, etc). Perturb each temperature as predicted to occur during on-orbit operations that impact thermal environment	300K <= External Target Temperature <= 360K		Estimate recovery period to achieve performance reqs.
SCT -162, SCT -164	Integrated Instrument	Thermal Vacuum	At each operational focal plane temperature set point	One external blackbody temperature; measurements over 40 minutes (may be sampled) in simulated orbits, three repeats at nominal temperature set point		Internal Blackbodies to be operated during these tests
SCT -166	Integrated Instrument	Thermal Vacuum	At each operational focal plane temperature set point	One external blackbody temperature continuous measurements over 40 minutes	Blackbody in T/V chamber	No FPA on-off cycling or resets during the measurements

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SCT -167	Observatory	Thermal Vacuum (high and low temperature plateaus)	At each operational focal plane temperature set point	One internal blackbody temperature	N/A	

3.4 Geometric Test Requirements

SCT-245 The Provider shall characterize the instrument's lines-of-sight (LOS) via measurements of each detector's LOS relative to the instrument coordinate system, to an accuracy ≤ 60 µrad (3-sigma), at the integrated instrument level.

Rationale: Band-to-band and image-to-image registration error budgets are driven by platform stability and line-of-sight knowledge and stability. The current error budgets assume 60 µrad (3-sigma) thermal LOS knowledge and 27 µrad (3-sigma) stability. On-orbit results from ETM+ showed that the thermal band is much more difficult to calibrate due to the poor correlation with the other multispectral bands.

Note: The use of on-board TDI may effectively create "synthetic" detectors from the combined output of multiple physical detectors. If this is the case, the geometric properties of the "synthetic" detectors will be derived from the physical detector lines-of-sight by analysis.

SCT-248 The Provider shall characterize the relative stability of the detector lines of sight by measuring the relative locations of a selected set of detectors from each band and each SCA at the nominal, maximum and minimum expected operating temperatures, to an accuracy ≤ 27 µrad (3-sigma), at integrated instrument or observatory level, post-vibration.

Rationale: Line-of-sight stability (over the range of expected operating temperatures) of 27 µrad (3-sigma) or better is required by the current band registration and image registration error budgets.

SCT-249 The selected set of detectors shall, at a minimum, bound the set of active detectors for each band on each SCA.

SCT-250 The selected set of detectors shall include a sampling of interior detectors such that no selected detector is more than 64 IFOVs from another selected detector.

SCT-252 The Provider shall measure the alignment of the instrument optical axes relative to the instrument alignment reference / alignment cube.

Rationale: The prelaunch alignment of the TIRS instrument to the OLI instrument is an initial measurement used to get the on-orbit calibration procedure started. The actual instrument alignment is expected to shift due to launch and zero-G release. This measurement is the instrument portion of the overall TIRS to OLI alignment measurement. The error budgets are

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based on on-orbit alignment calibration of the thermal instrument relative to the reflective instrument, so the accuracy of the prelaunch measurements is not critical.

SCT-254 The Provider shall demonstrate the ability to reconstruct and register images in both thermal bands from data collected under conditions that simulate the on-orbit target motion

Rationale: This test is intended to verify the integrity of the instrument-to-recorder data path.

Note: This demonstration may be performed in segments over the full FOV of the instrument.

SCT-257 The Provider shall characterize the detector-sampling timing pattern, to an accuracy of 1.5 milliseconds (3-sigma) or better, via measurement of any detector-specific electronic delays, sample phasing (e.g., even/odd detector timing offsets), and frame rate (i.e., time between samples) for each detector.

Rationale: Detector to detector timing/latency variations must not significantly degrade the line-of-sight knowledge of 60 μrad (3-sigma). Timing knowledge to 1.5 milliseconds corresponds to an additional LOS uncertainty of approximately 15 μrad.

4 Thermal Band On-Orbit Commissioning Phase Test Requirements

4.1 Spatial Test Requirements

SCT-261 The Provider shall examine the stray light and ghosting of the instrument using the moon, using data acquired at least 16 days apart.

4.2 Radiometric Test Requirements

SCT-263 The Provider shall validate the radiometric sensitivity model for the instrument thermal environment, i.e., the contributions of instrument emitted radiance to the instrument response.

SCT-264 The Provider shall validate the recovery time that it takes to return to nominal image performance after routine planned operations such as decontamination mode, off-nadir collects longest period, and other bus maneuvers that support OLI solar and lunar collects.

SCT-265 The Provider shall characterize any variations in detector responsivity over a minimum of 2 instrument out gassing (decontamination) cycles, if outgassing is required.

SCT-266 The Provider shall characterize the relative detector response for detectors within a band and update the calibration parameters to correct pixel-to-pixel non-uniformity as necessary. (including one demonstration of FPA diagnostic collection when looking at on-board Blackbodies)

SCT-267 The Provider shall characterize both the coherent and total noise of the instrument at a minimum of three radiance levels between 260K and 330K at least twice with the data acquired at least 16 days apart.

SCT-268 The Provider shall characterize: 1) the calibration stability and 2) the 1/f noise parameters for all detectors, over 3 orbits, at least twice, with the data acquired at least 16 days apart.

SCT-269 During the imaging-related maneuvers, e.g. lunar scans and off-nadir views for the reflective bands, the Provider shall characterize the stability of the thermal bands and the thermal calibration sources.

SCT-270 If Landsat-7 is still operational, the Provider shall support collection of TIRS data of common ground targets within 20 minutes of the Landsat-7 ETM+ acquisitions.

SCT-271 The Provider shall update the detector operability status list with newly identified dead, inoperable, and out-of-spec detectors for each band.

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4.3 Geometric Test Requirements

SCT-273 The Provider shall characterize the instrument to Attitude Determination System Reference alignment.

Rationale: The instrument alignment is expected to change due to launch shift and zero-G release, so an on-orbit update is required to achieve the required on-orbit geodetic accuracy performance. The thermal instrument alignment is expected to be inferred from the thermal to reflective band alignment (see next requirement) and the reflective instrument alignment calibration rather than being measured directly. The accuracy is here left as a component of the overall geodetic error budget to be determined by the Provider. Internal error budgets call for an alignment calibration accuracy of 75 microradians (3-sigma) derived as the RSS of the reflective instrument alignment calibration accuracy (45 microradians) and the thermal to reflective band alignment calibration accuracy (60 microradians).

SCT-275 The Provider shall characterize the thermal band detector arrays lines of sight relative to each other and to the reflective bands, using ground targets, at least twice, and using data acquired at least 16 days apart.

Rationale: The prelaunch line-of-sight calibration could change on-orbit due to the reaction of the optical system to launch and/or zero-G release. Any such changes would be expected to be slowly varying (not detector-by-detector) and subject to calibration using SCA-level on-orbit adjustments (as was done for the ALI). In the case of the thermal band, the thermal band to reflective band alignment calibration also provides the information needed to update the instrument alignment calibration (see previous requirement). The accuracy is here left as a component of the overall band registration error budgets to be determined by the Provider. Internal error budgets call for a thermal band to reflective band alignment calibration accuracy of 60 microradians (3-sigma) and a thermal band to thermal band alignment calibration accuracy of 36 microradians (3-sigma).

Note: The use of on-board TDI may effectively create “synthetic” detectors from the combined output of multiple physical detectors. If this is the case, the geometric properties of the “synthetic” detectors will be derived from the physical detector lines-of-sight by analysis.

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