Technical Note of

Temperature Drift Correction Module Calibration Data

---------- **Version 3.0.0**

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1. The Module

Here is a brief summary of the module. The details can be found in Ref. 1.

The temperature drift correction module is in both the photometer (PHOT) scan-map pipeline and the spectrometer (SPEC) pipeline. In the photometer scan-map pipeline, it is executed after the flux conversion module and the resulted correction is in Jy. In the spectrometer pipeline, on the other hand, the module is executed after the nonlinearity correction module and the temperature drift correction is in the units of Volt. Also, the module works in two bias modes: "nominal mode" and "bright source mode". This document covers all these cases.

The module corrects the low frequency correlated noise due to bath temperature variation. In the "nominal" bias mode the correction, which is to be **subtracted** from individual detector signal timelines, is estimated using the thermistor signal timelines. In the "bright source" bias mode, it is estimated using the dark detector signal timelines. The calculation includes the following steps:

- For each thermistor/dark-detector, its timeline $V_T(t)$ (in units of voltage) is binned. The bin width, Δt (in seconds), is an input parameter of the module. Taking the averaged signals in these bins as grid points, a SPLINE interpolation is applied to derive a smooth fit. In case that the timeline is too short for a SPLINE fit (i.e. the duration $< 3 \times \Delta t$), the smoothing was done through a linear regression of the individual data points (without bin-averaging). The smoothed timeline, denoted as $\underline{V_T}(t)$, specifies the bath temperature drift with time.
- There are two thermistors (T1 & T2)/dark-detectors (DP1 & DP2) for each detector array. If only one of them is exploited, the temperature drift correction, Q_T, is estimated as follows (see Section 3 for details):

$$Q_T(t) = A \times (\underline{V_T}(t) - V_{T0}) + \frac{B}{2} \times (\underline{V_T}(t) - V_{T0})^2$$

   where A and B are detector specific parameters, $\underline{V_T}(t)$ the smoothed timeline of the chosen thermistor/dark-detector, and V_{T0} a reference signal. A, B and V_{T0} are provided by the calibration product. Q_T is in the units of Jy for PHOT pipeline and Volt for SPEC pipeline.
- The module allows 3 different methods to derive Q_T: (1) it equals to the correction obtained using T1/DP1 timeline ('T1' method), (2) it equals to the correction obtained using T2/DP2 timeline ('T2' method), and (3) the average of the above two ('T1+T2' method). For each array, a metadata keyword, *thermistorSelect*, in the corresponding dataset within the calibration product specifies the method being used in the module.

- For SCANMAP pipeline in nominal mode, when all thermistors selected by *thermistorSelect* are either dead, saturated, or affected by signal jumps, the module will use DP timelines to model the thermistor timelines. Using PSWT1 in PSW array as an example, the formula is as following:

$$(V_{T1}(t) - V_{T1,0}) = 0.5 \times \left[(V_{DP1}(t) - V_{DP1,0}) / \frac{dV_{DP1}}{dV_{T1}} + (V_{DP2}(t) - V_{DP2,0}) / \frac{dV_{DP2}}{dV_{T1}} \right]$$

where $V_{DP1}(t)$ and $V_{DP2}(t)$ are timelines of the DPs, $V_{DP1,0}$ and $V_{DP2,0}$ the reference voltages of the DPs, dV_{DP1}/dV_{T1} and dV_{DP2}/dV_{T1} the derivatives of V_{DP1} and V_{DP2} over V_{T1}. And then the module will carry out the calculations using these modelled thermistor timelines.

The module output is a product containing the corrected detector signal timelines $S_{corr}(t)$: $S_{corr}(t) = S_{input}(t) - Q_T(t)$.

2. Data Format of Calibration Products

There are four input calibration products for this module, two (one for each bias mode) for the photometer scan map pipeline and the other two for the spectrometer pipeline.

2.1. Calibration products for the photometer pipeline

The two calibration products are the instances of the same class *PhotTempDriftCorr,* with different values of the metadata keyword *biasMode*: *biasMode = "nominal"* for the nominal mode, and *biasMode = "bright"* for the bright source mode. They have the same format. There are three TableDatasets, corresponding to the three arrays (PSW, PMW, PLW), respectively. Each TableDataset has a MetaData and a table. Parameters applicable to the whole array are given in the MetaData. Parameters applicable only to individual detectors are listed in the table, one row for a detector. Therefore, the number of rows equals to the number of detectors in the array, excluding the resistors, thermistors, and dark detectors. The following two tables, using PSW as an example, explain the data entries in the MetaData and in the table, respectively.

Table 2.1.1 Rows in the MetaData

Row	Parameter name	Explanation
1	pswT1RefVoltage	Double. Reference voltage of the thermistor T1.
2	pswT1RefVoltageError	Double. Error (only informative, not used in the module).
3	pswT1RefVoltageFlag	Boolean. Quality flag ('false' means bad data).
4	pswT2RefVoltage	Double. Reference voltage of the thermistor T2.
5	pswT2RefVoltageError	Double. Error (only informative, not used in the module).
6	pswT2RefVoltageFlag	Boolean. Quality flag ('false' means bad data).
7	pswDP1RefVoltage	Double. Reference voltage of the dark detector DP1.
8	pswDP1RefVoltageError	Double. Error (only informative, not used in the module).
9	pswDP1RefVoltageFlag	Boolean. Quality flag ('false' means bad data).
10	pswDP2RefVoltage	Double. Reference voltage of the dark detector DP2.
11	pswDP2RefVoltageError	Double. Error (only informative, not used in the module).
12	pswDP2RefVoltageFlag	Boolean. Quality flag ('false' means bad data).
13	thermistorSelect	String. Specify the method to be used (3 options: 'T1', 'T2', 'T1+T2').
14	dVDP1overdVT1	Double. First order derivative of DP1 voltage against T1 voltage.
15	dVDP1overdVT1Error	Double. Error (only informative, not used in the module).
16	dVDP1overdVT1Flag	Boolean. Quality flag ('false' means bad data).
17	dVDP2overdVT1	Double. First order derivative of DP2 voltage against T1 voltage.
18	dVDP2overdVT1Error	Double. Error (only informative, not used in the module).
19	dVDP2overdVT1Flag	Boolean. Quality flag ('false' means bad data).
20	dVDP1overdVT2	Double. First order derivative of DP1 voltage against T2 voltage.

21	dVDP1overdVT2Error	Double. Error (only informative, not used in the module).
22	dVDP1overdVT2Flag	Boolean. Quality flag ('false' means bad data).
23	dVDP2overdVT2	Double. First order derivative of DP2 voltage against T2 voltage.
24	dVDP2overdVT2Error	Double. Error (only informative, not used in the module).
25	dVDP2overdVT2Flag	Boolean. Quality flag ('false' means bad data).

Table 2.1.2. Columns in the table

Column	Parameter name	Explanation
1	Index	
2	names	String. Detector names
3	aT1	Double. The A parameter for 'T1' method.
4	aT1Error	Double. Error of aT1 (only informative, not used in the module).
5	bT1	Double. The B parameter for 'T1' method.
6	bT1Error	Double. Error of bT1 (only informative, not used in the module).
7	abT1Flag	Boolean. Quality flag of aT1 and bT1 ('false' means these data are bad).
8	aT2	Double. The A parameter for 'T2' method.
9	aT2Error	Double. Error of aT2 (only informative, not used in the module).
10	bT2	Double. The B parameter for 'T2' method.
11	bT2Error	Double. Error of bT2 (only informative, not used in the module).
12	abT2Flag	Boolean. Quality flag of aT2 and bT2 ('false' means these data are bad).

2.2. Calibration products for the spectrometer pipeline

The class defining the products is *SpecTempDriftCorr*. Its structure is similar to *PhotTempDriftCorr*. Each of the two products (for nominal mode and bright source mode, respectively) has two TableDatasets corresponding to the spectrometer arrays SSW and SLW, respectively. Each TableDataset has a MetaData and a table. They have the same format as those in *PhotTempDriftCorr* (see Table 2.1.1 and Table 2.1.2).

3. Procedure

3.1. Equations and definitions of parameters

Define V as the voltage of a detector and V_T the voltage of a thermistor (or of a dark-detector in case of bright source mode) in the same array. The temperature drift correction for the detector is equal to:

$$Q_T = \int_{V_{T0}}^{V_T} \gamma(V_T) dV_T \qquad (1)$$

where

$$\gamma(V_T) = f \frac{\partial V}{\partial V_T}, \qquad (2)$$

and f is the inverse responsivity function (Ref. 2):

$$f = f(V) = \frac{d\overline{S}}{dV} \quad . \tag{3}$$

Note that the detector voltage V depends on both the optical load q and the array bath temperature T (specified by V_T). The function γ depends only on V_T, not on q. When the variation of the bath temperature δT is less than 10 mK, γ can be approximated by the following linear function (i.e. the first two terms of its Taylor expansion around V_{T0}) to the accuracy of better than 2%:

$$\gamma(V_T) = A + B \times (V_T - V_{T0}) \tag{4}$$

Replacing V_T by the smoothed timeline $\underline{V_T}$ (to minimize the r.m.s error of $\underline{V_T}$), the correction is then estimated by the following formula:

$$Q_T(t) = A \times (\underline{V_T}(t) - V_{T0}) + \frac{B}{2} \times (\underline{V_T}(t) - V_{T0})^2 \quad . \tag{5}$$

Finally, the corrected detector signal timeline is:

$$S_{corr}(t) = S_{input}(t) - Q_T(t). \tag{6}$$

3.2. Calibration of the parameters

3.2.1. Dependence on the calibration products of the flux conversion module (PHOT) and the nonlinearity correction module (SPEC)

The calibration of the parameters in this module invokes parameters that specify the inverse responsivity function f(V). These parameters and the reference voltages of the thermistors and of the dark detectors are taken directly from the corresponding calibration products of the flux conversion module (PHOT) and the nonlinearity correction module (SPEC). There is a consistency check within the module to make sure that the version of the calibration product being used is consistent with that of the calibration product used in the flux conversion module (or the nonlinearity module for SPEC pipeline).

3.2.2. Thermistor/dark-detector timeline smoothing time span: Δt

From analysis of PFM5 dark-noise test data, we found a range of *5s < Δt < 20s* for the optimal temperature drift correction. The initial default value is set to *Δt =10s*. **Analyses carried out using data obtained in the PV phase have shown that the value of time span Δt =5s provided better corrections. The current default is Δt =5s.**

3.2.3. Selection of thermistors/dark-detectors: thermistorSelect

In order to avoid mal-functional thermistors/dark-detectors (as found in the PFM5 tests), the following initial default values of *thermistorSelect* have been assigned:
- Nominal mode, PHOT [PSW, PMW, PLW]: ['T1+T2', 'T1', 'T1+T2']
- Nominal mode, SPEC [SSW, SLW]: ['T1+T2', 'T1+T2']
- Bright mode, PHOT [PSW, PMW, PLW]: ['T1+T2', 'T1+T2', 'T1+T2']
- Bright mode, SPEC [SSW, SLW]: ['T1+T2', 'T1']

3.2.4. Reference voltages of thermistors and dark detectors

These are copied from corresponding calibration products of the flux conversion module (or the nonlinearity correction module for the SPEC pipeline).

3.2.5. Parameter A

Every detector has its own A and B parameters. By definition (Eqs (2) – (4)),

$$A = \gamma(V_T = V_{T0}) = [f \frac{\partial V}{\partial V_T}]_{V_T = V_{T0}} \qquad . \qquad (7)$$

In PFM5 dark noise tests, the V vs. V_T correlation has shown a nearly perfect linear form. No curvature was detected even for test data with bath temperature variations as large as $\delta T \sim 4$ mK. Therefore we assume $\partial V / \partial V_T = constant$. It can be determined by the linear regression of the V vs. V_T correlation using the calibration data. Note that the optical load should be constant during the calibration observations to ensure that the variation of V is solely due to the variation of the bath temperature. In this case, each detector has a unique voltage signal V for $V_T = V_{T0}$, which in turn determines the value of $f = f(V)$. Optimally, the calibration observations should cover a V_T range as wide as possible in order to achieve high precision for the estimate of $\partial V / \partial V_T$.

3.2.6. Parameter B

$$B = \left[\frac{d\gamma}{dV_T} \right]_{V_T = V_{T0}} = \left[\frac{\partial f}{\partial V_T} \right]_{V_T = V_{T0}} \frac{\partial V}{\partial V_T} = \left[\frac{df}{dV} \right]_{V_T = V_{T0}} \left(\frac{\partial V}{\partial V_T} \right)^2 . \qquad (8)$$

Note that we have assumed $\partial V / \partial V_T = constant$. Taking the same approximation as adopted in the flux conversion module (or in the nonlinearity module in SPEC pipeline), $f(V) = K_1 + K_2/(V - K_3)$, we have:

$$\frac{df}{dV} = \frac{-K_2}{(V - K_3)^2} \qquad (9)$$

and

$$B = \frac{-K_2}{[V(V_T = V_{T0}) - K_3]^2} \left(\frac{\partial V}{\partial V_T} \right)^2 \qquad . \qquad (10)$$

The B parameters are calibrated using the same observations that calibrate the A parameters.

3.2.7. First order derivatives of DP voltages against thermistor voltages

These parameters are measured from the slopes of linear regressions of DP signals against thermistor signals, taken from calibration observations which provide the reference voltages $V_{T,0}$'s and $V_{DP,0}$'s.

3.3. Initial calibration products

In the initial delivery the parameters were not calculated using any observations. Instead, they were calculated using the bolometer model (Ref. 3) with the PFM5 detector parameters (Ref. 4). All variables specifying the physical conditions (e.g. bias voltages and bath temperatures) were taken from the corresponding calibration products of flux conversion module (PHOT) and nonlinearity correction module (SPEC). Please see Ref. 5 and Ref. 6 for details.

3.4. This Delivery:

1. SCalPhotTempDriftCorr_Nominal_20090819_3.0.0.fits
    - Photometer, Nominal mode.
    - $V_{T,0}$, $V_{DP,0}$, and K values from SCalPhotFluxConv_nominal_20090819_vtestGJB_16Jul10.fits.
    - Slopes (dV/d_{VT}) were calculated using calibration data obtained on OD152/3.
    - Added first order derivatives of DP voltages against thermistor voltages, their errors and flags to the metadata of each array.

4. References

1. Pearson, C. 2009, *Spire Pipeline Description,* SPIRE-RAL-DOC-002437, Issue 2.0, 31 January 2009.
2. Griffin, M. 2008, *The SPIRE Analogue Signal Chain and Photometer Detector Data Processing Pipeline,* SPIRE-UCF-DOC-002890, Issue 6.0, 21 November 2008.
3. Mather, J. 1984, *Applied Optics*, v23, 584.
4. Nguyen, H., et al. 2007, *Notes on Load Curve Analysis and Delta T Measured Across Thermal Strip.*
5. Lu, N. 2009, *Technical Note on the SCalPhotFluxCov Calibration Products*, v1.8, May 6, 2009.
6. Lu, N. 2009, *Technical Note on the SCalSpecNonLinCorr Calibration Products*, v1.8, May 6, 2009.