TECHNICAL NOTE ON SCALSPECNONLINCORR CALIBRATION PRODUCTS (VERSION 1.6)

N. Lu/NHSC/IPAC (lu@ipac.caltech.edu)
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1 INTRODUCTION

The purpose of the SPIRE pipeline module "specNonLin" is to "linearize" a detector voltage time line by correcting for the detector nonlinear responsivity. The numeric values of the linearized voltages are proportional to the corresponding detector optical loads. The module calibration is based on the following algorithm (cf. reference AD01):

The inverse bolometer responsivity, dQ/dV, can be expressed as a function of the bolometer voltage V as

$$dQ/dV = K1' + K2'/(V-K3), \qquad \text{...... (1)}$$

between two limiting voltages Vmin and Vmax, where Q stands for the detector optical load and K1', K2' and K3 are 3 parameters to be fit in the PV phase.

For the SPIRE spectrometer, we normalize dQ/dV in eq. (1) by its value at an arbitrary reference voltage V_R:

$$(dQ/dV)/(dQ/dV)_R = [K1'/(dQ/dV)_R] + [K2'/(dQ/dV)_R]/(V-K3).$$

Let's denote $V' \equiv Q/(dQ/dV)_R$, $K1 \equiv K1'/(dQ/dV)_R$, and $K2 \equiv K2'/(dQ/dV)_R$. We then have

$$dV'/dV = K1 + K2/(V-K3), \qquad \text{....... (2)}$$

One can call V' a linearized voltage as its value is proportional to the optical load Q. Note that, since the conversion from V' to the final flux density is done in a separate module later in the pipeline, one is free to apply any arbitrary (dimensionless) scaling factor to eq. (2).

The calibration product for the module will contain K1, K2, K3 and V_0, which is a "zero-point" reference voltage, chosen to be close to the voltage reading (at a fixed detector bath temperature T_0) of the operating background from the telescope and SCALs. The module then integrates Eq. (2) from V_0 to V to convert each sample voltage V to a linearized voltage V':

$$V' = \int_{Vo}^{V} (dV'/dV)\, dV = K1(V - Vo) + K2 \ln\left(\frac{V - K3}{Vo - K3}\right), \qquad \text{..... (3)}$$

2 OBSERVING MODES

We generate separate calibration products for the two SPIRE observing modes – normal and bright source. The bright-source mode has LIA de-phased at 70 degrees. This reduces both the measured voltage and effective detector responsivity by a factor of 2.9 (cf. RD02).

3 DATA FORMAT OF THE CALIBRATION FILE

3.1 File Format

The calibration file delivered is a binary FITS extension file written within HCSS as a FITS binary archive of a calibration product that is an instance of the class "herschel.spire.ia.dataset.SpecNonLinCorr." In the following illustration, this product is named "nonLinCorrTable."

```
directory = "[set to the directory path to the archive FITS file]"
version = "1.5"
filename = java.io.File(r"%sSCalPhotFluxConv_v%s.fits"%(directory,version))
fitsWriter = herschel.ia.io.fits.FitsArchive()
fitsWriter.save(filename.toString(), nonLinCorrTable)
```

This FITS file can be directly imported to the pipeline as in the following illustration:

```
from herschel.ia.io.fits import FitsArchive
fa = FitsArchive()
nonLinCorrTable  =  fa.load("ScalSpecNonLinCorr_v1.5.fits")
sdt = specNonLin(sdt, table=nonLinCorrTable)
```

3.2 Meta Data and Data Columns

3.2.1 FITS Primary Header (or Meta Data)

The primary header of the calibration file contains the following meta data:

Table 3.2.1.1 Meta Data

Row	Parameter name	Explanation
1	type	SpecNonLinCorr
2	creator	$Id: makeSCalNonLinCorr.py,v 1.2 2009/02/11 15:06:42 NLu $
3	creationDate	2009-02-12T19:46:49.874000Z (1613159243874000)
4	description	Spectrometer Non-Linearity Correction Calibration Table
5	instrument	SPIRE

6	modelName	PFM
7	startDate	2005-02-22T00:00:00.000000Z (1487721632000000)
8	endDate	2020-01-01T00:00:00.000000Z (1956528034000000)
9	version	Version number of the calibration table.
10	respControlStamp	A date parameter stamp for matching the right version of the temperature drift calibration product.
11	biasMode	Set to either "Nominal" or "Bright."
12	sswBiasAmpl	SSW bias voltage amplitude in units of volts.
13	slwBiasAmpl	SLW bias voltage amplitude in units of volts.
Non-mandatory Meta Data:		
14	degreeLIADephasing	LIA dephasing angle in degrees.
15	sswBathTemp	SSW detector reference bath temperature to which V_0 refers.
16	slwBathTemp	SLW detector reference bath temperature to which V_0 refers.
17	sourceTable	Set to the file name of the source table from which this calibration product was created. This is for the author's bookkeeping purpose only.

3.2.2 Binary Table Extensions (or TableDatasets)

There are 2 binary table extensions in the FITS file. The first is for SSW and the second for SLW.

Each binary table extension contains the following meta data and data columns:

Table 3.2.2.1 Meta Data

Row	Parameter name	Explanation
1	ss(l)wT1RefVoltge	SS(L)W thermistor T1 reference voltage in volts.
2	ss(l)wT1RefVoltgeError	SS(L)W thermistor T1 reference voltage uncertainty in volts.
3	ss(l)wT1RefVoltgeFlag	SS(L)W thermistor T1 reference voltage boolean flag (0 indicates invalid data).
4	ss(l)wT2RefVoltge	SS(L)W thermistor T2 reference voltage in volts.
5	ss(l)wT2RefVoltgeError	SS(L)W thermistor T2 reference voltage uncertainty in volts.
6	ss(l)wT2RefVoltgeFlag	PS(L)W thermistor T2 reference voltage boolean flag (0 indicates invalid data).
7	ss(l)wDK1RefVoltge	SS(L)W dark channel DK1 reference voltage in volts.
8	ss(l)wDK1RefVoltgeError	SS(L)W dark channel DK1 reference voltage uncertainty in volts.
9	ss(l)wDK1RefVoltgeFlag	SS(L)W dark channel DK1 reference voltage

		boolean flag (0 indicates invalid data).
10	ss(l)wDK2RefVoltge	SS(L)W dark channel DK2 reference voltage in volts.
11	ss(l)wDK2RefVoltgeError	SS(L)W dark channel DK2 reference voltage uncertainty in volts.
12	ss(l)wDK2RefVoltgeFlag	SS(L)W dark channel DK2 reference voltage boolean flag (0 indicates invalid data).

Table 3.2.2.2 Data Columns

Column	**Parameter name**	**Explanation**
1	names	Detector channel names (e.g., SSWA1).
2	v0	Zero point voltage V_0, in units of V.
3	v0Error	V_0 error, in V.
4	v0Flag	Boolean logic flag for V_0 (set to false if the V_0 value is invalid).
5	k1	K1 parameter, dimensionless.
6	k1Error	Error of K1, dimensionless.
7	k2	K2 parameter, in V.
8	k2Error	Error of K2, in V.
9	k3	K3 parameter, in V.
10	k3Error	Error of K3, in V.
11	kFlag	Boolean logic flag for the K parameters (set to false if the K values are invalid).
12	vMin	The lower voltage limit Vmin of this calibration table, in V.
13	vMax	The upper voltage limit Vmax of this calibration table, in V.

4 Derivation of the Calibration Data

For this pre-launch version of the calibration product, we reply on the bolometer model constructed on the PFM5-based detector parameters. (For a few channels that have no PFM5 parameters, we used their BoDac values.)

The following tables summarize the key assumptions made in our calculation. These assumptions are mostly based on the reference AD01 or SPIRE ground-based testing data.

Table 4.1 Key Assumptions for the Normal Observing Mode

SPIRE model	PFM5
T_0, the bath temperature for both SSW and SLW	0.310K
V_b, the bias voltage amplitudes (SSW, SLW)	(31.1, 31.1) mV
Qmin, the lower limits in optical power for responsivity fitting (SSW, SLW)	(2.05, 2.45) pW
Qmax, the upper limits in optical power for responsivity fitting (SSW, SLW)	(10.25, 12.25) pW
Q_0, the optical powers of the nulled telescope+SCAL (SSW, SLW)	(4.10, 4.90) pW
Q_R, the optical powers for responsivity normalization (SSW, SLW)	(4.10, 4.90) pW
LIA de-phasing angle	0 degrees

Table 4.2 Key Assumptions for the Bright-Source Observing Mode

SPIRE model	PFM5
T_0, the bath temperature for both SSW and SLW	0.310K
V_b, the bias voltage amplitudes (SSW, SLW)	(31.1, 31.1) mV
Qmin, the lower limits in optical power for responsivity fitting (SSW, SLW)	(2.05, 2.45) pW
Qmax, the upper limits in optical power for responsivity fitting (SSW, SLW)	(20.5, 20.5) pW
Q_0, the optical powers of the nulled telescope+SCAL (SSW, SLW)	(4.10, 4.90) pW
Q_R, the optical powers for responsivity normalization (SSW, SLW)	(4.10, 4.90) pW
LIA de-phasing angle	70 degrees

The following steps explain how we derived the calibration data:

- Using the bolometer temperature T_0 and the bias voltage amplitude V_b given in Table 3.1, we derived an inverse responsivity, dQ/dV (in units of pW/V), and bolometer voltage, V (in units of V), for each and every input optical load Q between Qmin and Qmax. This dQ/dV is then normalized by its value at the optical load Q_R.

- For the bright-source mode, dV/dQ and V are both further reduced by a factor “dPhase” based on the LIA de-phasing angle A. For A = 70 degrees, dPhase = 2.9 (see RD2).

- Fit the normalized dQ/dV-vs.-V curve to the function given in eq. (2) between Vmin and Vmax, where the two limiting voltages correspond to Qmax and Qmin, respectively. This involves using the IDL facility routine "lmfit.pro," assuming a set of initial values for K1, K2 and K3. The result is a set of the best-fit values for K1 (dimensionless), K2 (in V) and K3 (in V) and their estimated uncertainties. (Note: These uncertainties scale as SSD/sqrt(N), where SSD is the sample standard deviation and N is the sample size. So it depends not only on the fit residuals, but also on N. Since N is an arbitrary number in such an exercise (we used N = 50), these uncertainty values should be taken only for what they are actually worth.)

- To have reasonable Qmin and Qmax for the normal observing mode, we have simply set in Table 4.1 Qmin and Qmax to equal to 50% and 250% of the telescope+SCAL background, respectively. For the bright-source mode, we used the same Qmin, but increased Qmax by a factor of 2.

- The reference voltage (V_0) was set to the voltage corresponding to the optical load Q_0. Its uncertainty (v0Error) is simply set to 0.1%V_0.

- The minimum and maximum ratios (Rmin and Rmax, respectively) of the fit to the model curve between Vmin and Vmax are used as practical indicators on the goodness of the fit. The fit residuals range from less than 0.1% for most SSW and many SLW channels, to a few times 0.1% for some SLW channels.

5 REFERENCES

5.1 List of Applicable Documents

- (AD1) SPIRE Analogue Signal Chain and Photometer Detector Data Processing Pipeline (SPIRE-UCF-DOC-002890, Issue 4, 20 February 2008)
- (AD2) SPIRE Pipeline Description (SPIRE-RAL-DOC-002437)
- (AD3) SPIRE Data Processing Pipeline Module Requirements (SPIRE-ICS-DOC-002998)

5.2 List of Reference Documents

- (RD1) SPIRE Data Products Specification (SPIRE-RAL-DOC-002005)
- (RD2) http://www.submm.caltech.edu/~cdd/SPIRE/20090203_bright_source_mode/