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Herschel SPIRE-DRCU

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SCU QM1 Test Report

This document gives the test report of the QM1 model of the System Control Unit (SCU), one of the 3 subsystems of the Herschel/SPIRE/DRCU system.

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1.1 Applicable documents

1.1.1 Specification documents

- AD 1 : « DRCU Subsystem Specification », Sap-SPIRE-Cca-0025-00, V1.0.

1.1.2 Interface documents

- AD 2 : « DRCU Interface Control Document », Sap-SPIRE-Cca-0075-02, V1.0 ;
- AD 3 : « DPU Interface Control Document », SPIRE-IFS-PRJ-650, V1.0.

1.1.3 Technical documents

- AD 5 : « A Generic DPU Interface for SPIRE DRCU subsystems », SEDI-DRCU-OG-2002-1, V0.4 ;
- AD 6 : « Note on temperature measurement using CERNOX probe for the SPIRE and PACS instruments », C. CARA - 28/06/01 ;
- AD 7 : « The System Control Unit (SCU) », SEDI-SCU-MM-2002-1, V0.7.

1.2 SCU overview (reminder)

The Subsystem Control Unit (SCU) is an ancillary unit of the DRCU, in charge of various acquisition, control, support and monitoring functions, as specified in AD 1.

1.2.1 Acquisition and control functions

The SCU is in charge of the following low-level acquisition and control functions :

- Control and monitoring of the cryo-cooler heaters (recycling heater [SCU-FUNC-01], gas switch heater [SCU-FUNC-02] and FPU thermal strap heater [SCU-FUNC-03]) ;
- Control and monitoring of the photometer and spectrometer IR calibrators (PCAL, SCAL 2% and SCAL 4%) [SCU-FUNC-04] ;
- Acquisition of the FPU thermal sensors (thermometry subsystem) [SCU-FUNC-05, -06].

1.2.2 Support and monitoring functions

The SCU is in charge of the following low-level support and monitoring functions :

- Logical On/Off control of some PSU secondary power supplies (DCU-LIA P/S, MCU) [SCU-FUNC-13] ;
- SCU power supply monitoring [SCU-FUNC-07, -11] ;
- SCU and PSU electronics temperature monitoring [SCU-FUNC-07, -11] .

1.2.3 DPU interface functions

To support the above functions, the SCU decodes [SCU-FUNC-08] and responds [SCU-FUNC-09] to DPU commands, according to the DPU Cmd protocol. When in operation, it creates and produces a sequence of measurement Data Frames [SCU-FUNC-12], according to the DPU Data protocol. Each Data Frame carries the value of a relative Time Stamp, which is locally maintained in the SCU [SCU-FUNC-10].

1.2.4 Functional block diagram

The following diagram shows the functional organisation of the SCU.

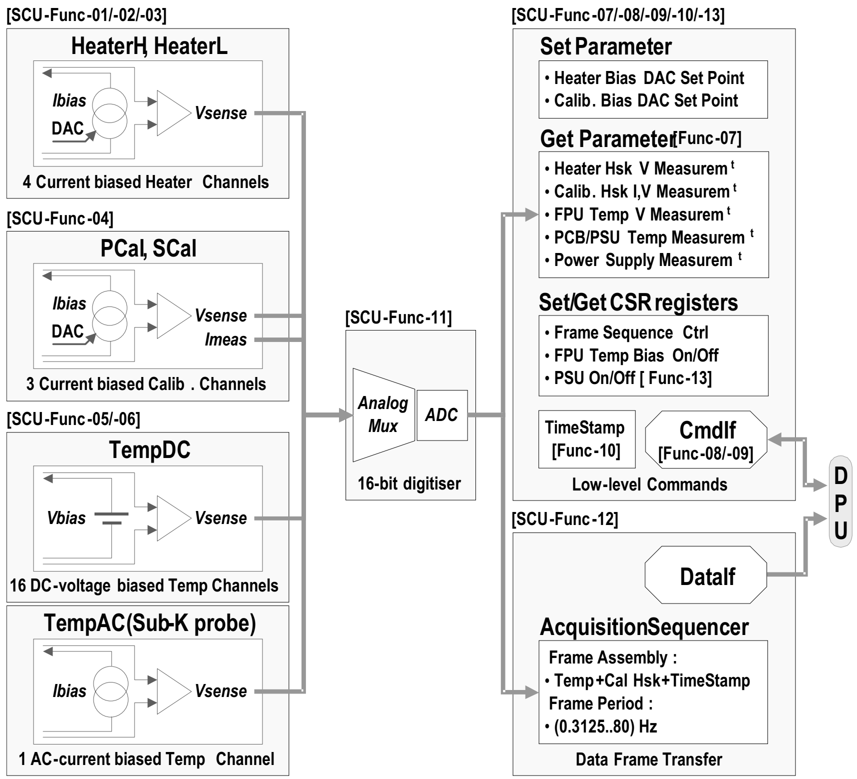


Figure 1 SCU Functional Block Diagram

1.2.5 Structural block diagram

The SCU is implemented as a set of two active electronic boards –Temp and CchkIf– connected to a passive backplane board –Bkpln– as shown in Figure 2 .

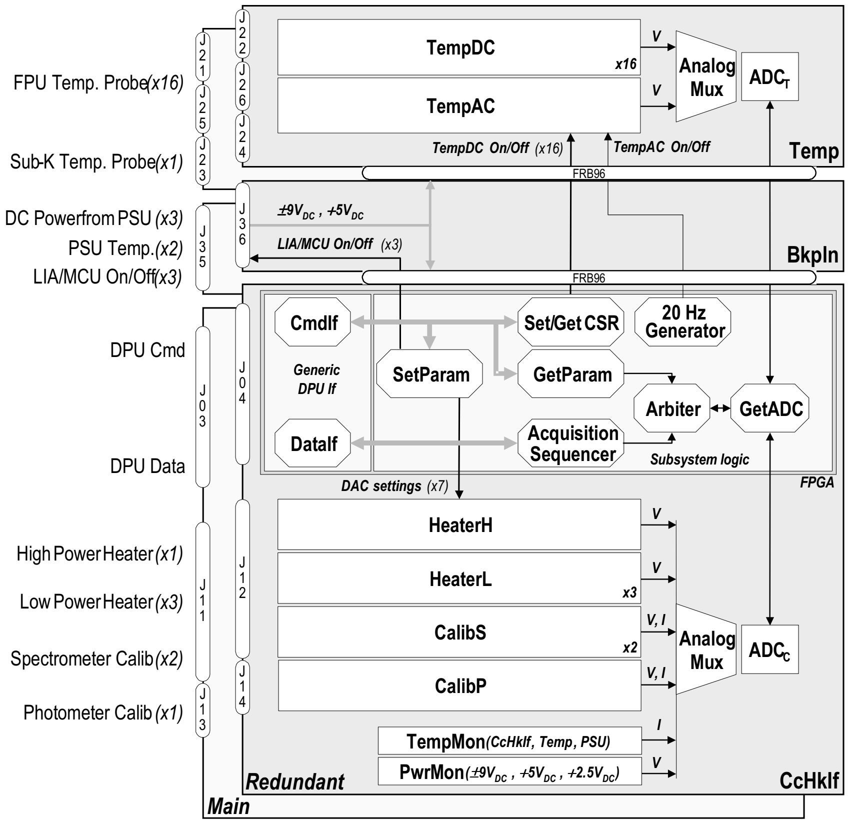


Figure 2 SCU Structural block diagram

The independent single-channel analogue signal conditioning circuits –TempDC, TempAC, HeaterH, HeaterL, CalibS, CalibP, TempMon and PwrMon– are supervised by the SCU Subsystem Logic. This logic is installed in a Field Programmable Gate Array (FPGA) logic cicuit.

1.2.6 Behaviour

The SCU is a slave device running under full supervision of the DPU software. Once initialised, it responds to DPU-initiated commands issued on the *Cmd Interface*. These commands first install the required configuration, and then start SCU operation.

1.2.6.1 Data frame sequence

When in operation, the SCU *Acquisition Sequencer* regularly prepares a well-defined *Data Frame* and autonomously transfers it to the DPU over the *Data Interface.* The frequency and duration of this *Data Frame* sequence are adjustable by configuration. The *Data Frames* are individually time stamped with a local clock value, which is also under control of the DPU software.

1.2.6.2 Subsystem parameter access

Asynchronous commands can be issued by the DPU at any time on the *Cmd* interface, to update or request a SCU parameter value.

1.2.6.2.1 Parameter update

SCU write-able parameters are updated immediately when the corresponding DPU write command is received and accepted, independent of the activity of the *Acquisition Sequencer*.

1.2.6.2.2 Parameter request

SCU readable parameters are provided when the corresponding DPU read command is received and accepted. However, the response time depends on the current activity of the *Acquisition Sequencer* when the request is issued. The SCU subsystem logic interleaves the atomic parameter sampling operations corresponding to either cyclic acquisition or asynchronous requests.

2 Tests: general

This section gives general information useful to understand the test results of the SCU channels.

2.1 ADC number representation

All SCU analogue parameters are converted to digital by 7809 16-bit ADC circuits. These ADCs are configured to produce 16-bit 2's complement numbers according to the ideal table shown in Table 1 .

Decimal	Hexadecimal	Voltage (V)
+32767	$7FFF	+5.000
…		…
1	$0001	+0.000153
0	$0000	0
-1	$FFFF	-0.000153
…	…	…
-32768	$8000	-5.000

Table 1 ADC number representation

The SCU analogue channels use distinct areas and directions in the ADC range. For clarity, these options are summarised in Table 2 . For Temp channels, the probe load resistance value is designated by R_L.

ADC range	Hex	Voltage (V)	Calibrator/Heater ADCv [ADCi]		FpuTemp ADCi		SubKTemp ADCv	
+32767	$7FFF	+5.000	Vmax [Imax]	*High DAC*	*Unused area*		Vmin	*Low R_L*
…		…	⇑	*Increasing DAC*			⇓	*Increasing R_L*
0	$0000	0	Vmin [Imin]	*Low DAC*	Imin	*High R_L*		
…	…	…	*Unused area*		⇓	*Decreasing R_L*		
-32768	$8000	-5.000			Imax	*Low R_L*	Vmax	*High R_L*

Table 2 SCU channel signal variation in ADC range

These ideal areas do not include possible offset errors. In the actual circuit, Vmin [Imin] for Calibrator/Heater channels may be slightly negative, and Imin for FpuTemp channels may be slightly positive.

2.2 Test conditions

The detailed SCU-QM1 tests described in this document were conducted at laboratory room temperature (~25 °C), with DC power +9V, -9V, +5V. Due to the limited available time, the

comprehensive analogue channel tests could not be repeated at various temperatures in thermal chamber. However, a final integration test at the FCU box level with a distinct setup (LTU+FPU simulator) has tracked channel response variation for a limited number of measurement points.

3 Calibrator/Heater tests

This section gives the test conditions and results for the Heater and Calibrator analogue channels.

3.1 Calibrator/Heater test configuration

The same test configuration is used for the 3 calibrator channels (PhCal, Scal2 and Scal4) and the 4 heater channels (EVHSHeat, SPHSHeat, TCHeater and SPHeater), which all behave as similar DAC-controlled current sources. Each channel is loaded with its nominal load resistor R_L. The actual current (I_L) and voltage (V_L) across the load are measured by external high-precision (GPIB-driven) instruments (Keithley model 6485 picoammeter and Keithley model 2750 multimeter), which give the I_K and V_K estimates.

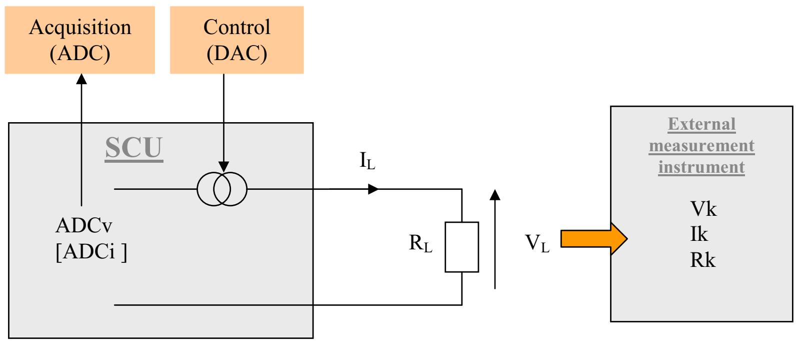


Figure 3 Cal/Heat test synoptics

For each measurement point, the SCU DAC value is first programmed to install the required current source setting point. After a programmable settling time interval, the external instruments are interrogated to obtain the Ik and Vk values. The SCU voltage monitoring measurement ADCv is readout. For calibrator channels, the SCU current monitoring measurement ADCi is also readout. The SCU TcuT and CcuT AD590 probe channels are readout to track the electronic board temperature. The measurement is time stamped and saved in a file for further analysis.

Various DAC sequences are applied, to provide linear ramping across the DAC range, to measure settling times and to measure stability.

The load resistance values used to obtain the following results are reported in Table 3 :

Channel	Specification Load	Test Load	Specification Harness	Test harness
SP heater	402 Ω	410.8 Ω	≤ 40 Ω	0 Ω
SPHS heater	402 Ω	405.0 Ω	≤ 100 Ω	0 Ω
EVHS heater	402 Ω	401.8 Ω	≤ 100 Ω	0 Ω
TC heater	6 kΩ	5999. kΩ	≤ 1 kΩ	0 Ω
PhCal	200 to 500 Ω	204.9 Ω	≤ 100 Ω	0 Ω
SCal 2%	500 Ω	509.9 Ω	≤ 100 Ω	0 Ω
SCal 4%	500 Ω	509.7 Ω	≤ 100 Ω	0 Ω

Table 3 Cal/Heat test configuration: load resistance values

3.2 Sorption Pump heater (SPHeater)

3.2.1 Specification (reminder)

The following table recalls the requirement for the cooler Sorption Pump high power heater [extracted from AD 1].

Type	Number	Heater Resistance	Lead resistance	Power	Max. Voltage	Interface type
Sorption Pump	1	402	≤ 40 Ω	0 to 500 mW	15V	2x2-wire

Table 4 SPHeater requirements

3.2.2 SPHeater test results

The following graphs show the transfer curves, the linearity of the current production, and the linearity of the voltage housekeeping measurements. For this channel, the current exceeds the picoammeter maximum range (20 mA) and is measured on a parallel shunt resistance.

3.2.2.1 DAC to current transfer curve: full range

Figure 4 shows an overview of the current variation obtained when ramping the DAC through the full [0..4095] range.

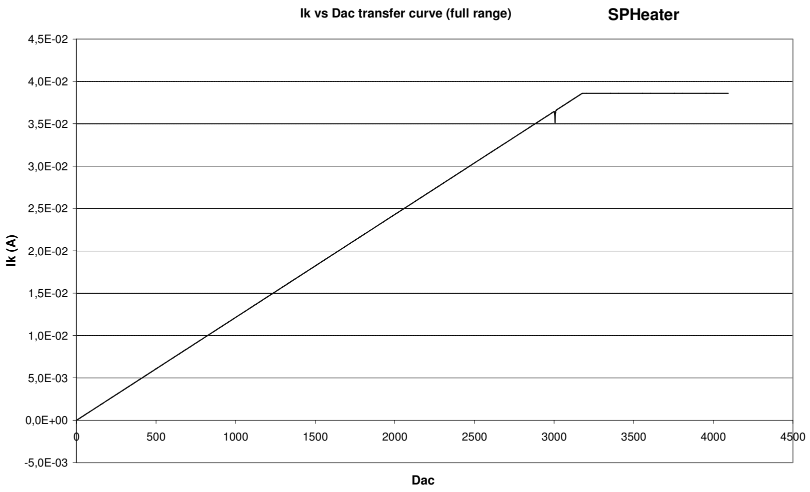


Figure 4 SPHeater: DAC to current transfer curve (full range)

In the conditions of the test (±9V nominal), the circuit saturates at 38.6 mA (DAC=3178, V_L=15.6V), and the power requirement of 0.5 W is already reached at DAC=2897 (I_L=.35.18 mA). Under worst case usage conditions (R_L + harness = 442 Ω, power lines +9V-0.1V,-9V+0.1V), the maximum current will be (15.6-0.2)/442=34.8 mA, and the required power will still be reached (0.535 W for the maximum power).

3.2.2.2 DAC to current transfer curve : low current

Table 5 shows the measurement figures for the current extinction at low DAC values. An ideal DAC step corresponds to 12.15 µA (see Table 6). The circuit cancels current for very low DAC values, providing effective extinction down to few nA, a small fraction of a DAC step. The linear current production starts from DAC value 5.

Dac	AdcV	Ik (A)	Vk (V)
0	-3	-2.334316E-09	-4.2418E-06
1	-3	1.782859E-09	-4.3045E-06
2	-3	-2.280984E-09	-3.2837E-06
3	-5	-2.193654E-09	-3.8750E-06
4	-4	2.268191E-09	5.8650E-04
5	23	3.819927E-05	1.5461E-02
6	22	5.051589E-05	2.0425E-02
7	33	6.259058E-05	2.5293E-02
8	45	7.501406E-05	3.0311E-02
9	53	8.702366E-05	3.5167E-02
10	61	9.923351E-05	4.0100E-02
11	69	1.112592E-04	4.4962E-02
12	79	1.235641E-04	4.9935E-02

Table 5 SPHeater: current extinction at low DAC values

Figure 5 shows the corresponding enlarged view of the DAC to current transfer curve.

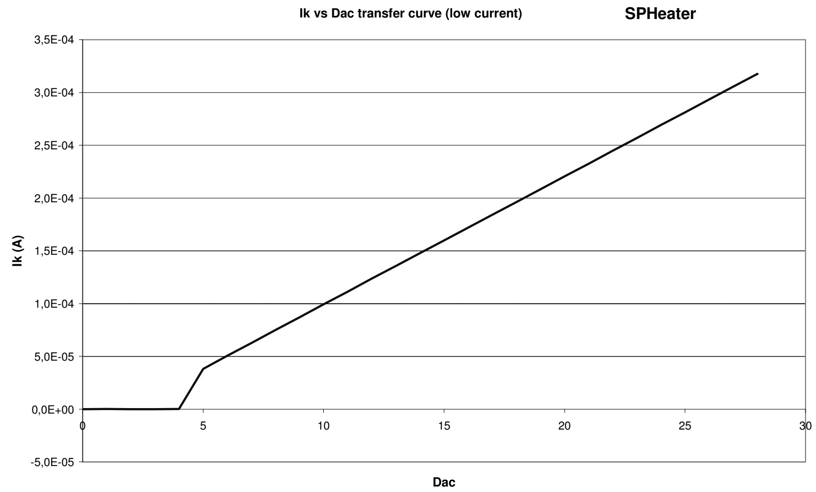


Figure 5 SPHeater: DAC to current transfer curve (low current)

3.2.2.3 DAC to current linearity

The parameters of the linear transfer function where obtained by linear regression, after discarding the measurement data corresponding to the current extinction area. Table 6 shows the linear fit results, as provided by the Microsoft Excel regression macro (Analysis Of Variance method).

Regression Statistics	
Multiple R	9.99999998E-01
R Square	9.99999996E-01
Adjusted R Square	9.99999996E-01
Standard Error	6.38108E-07
Observations	2894

	Coefficients	*Standard Error*
Intercept (p0)	-2.254E-05	2.4E-08
Slope (p1)	1.21532E-05	1.4E-11

Table 6 SPHeater: DAC to current linear fit results

The predicted current is I_{pred} (A) = p0 + p1*DAC.

The circuit shows excellent linearity, as shown by the RSquare parameter (fraction of variance explained by the linear dependence) which approaches 1 very closely. The residual RMS deviation from the fit (standard error) is less than 638 nA. The corresponding residual distribution is shown in Figure 6 , which shows that most of the variability is certainly due to the structural non linearity in the DAC circuit internals. The peak-to-peak residual error for this particular circuit is contained in a ±2 µA interval (~±1/6 DAC LSB step).

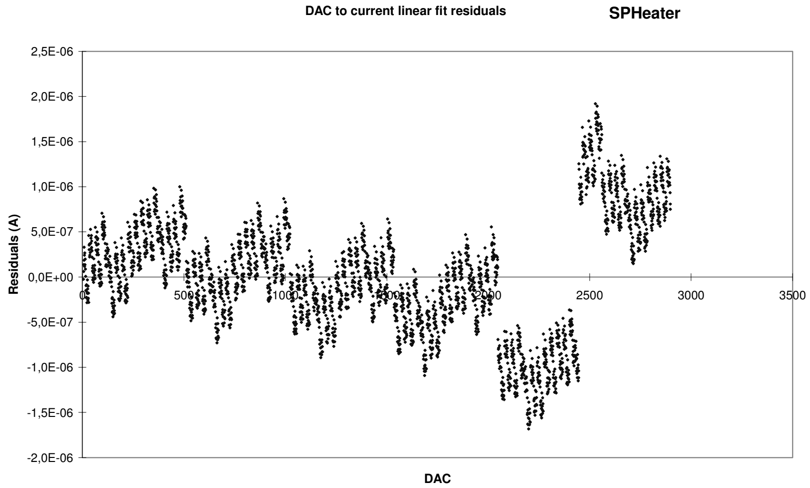


Figure 6 SPHeater: DAC to current linear fit residuals

3.2.2.4 Voltage measurement

The linear parameters of the ADCv voltage measurement, as a function of the actual voltage V_L across the load, are summarised in Table 7 .

Regression Statistics	
Multiple R	9.99999983E-01
R Square	9.99999967E-01
Adjusted R Square	9.99999967E-01
Standard Error	1.24413974
Observations	2961

	Coefficients	*Standard Error*
Intercept (p0)	-3.88	0.046
Slope (p1)	1630.112	0.0054

Table 7 SPHeater: Voltage to ADCv linear fit results

The predicted ADCv value corresponding to a voltage V_L across the R_L=410.8 Ω load is:

ADCv = round(p0 + p1* V_L) *[V_L expressed in V].*

The ADCstep voltage equivalent is 613.4 µV (1/p1). The observed residual deviation is 1.24 ADCstep RMS (less than ±4 ADCstep peak-peak) over the full DAC range.

Figure 7 shows the residuals of the linear fit in ADC steps.

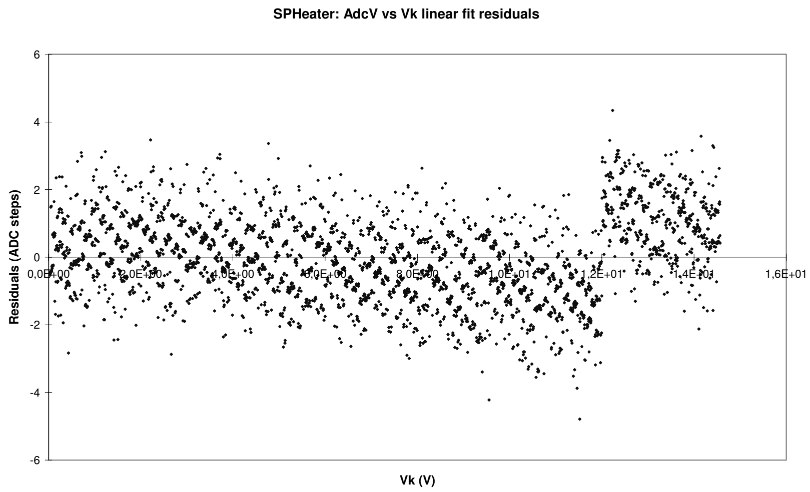


Figure 7 SPHeater: Voltage to ADCv linear fit residuals

3.3 EVHSHeat & SPHSHeat heaters

3.3.1 Specification (reminder)

The following table recalls the requirement for the Heat Switch low power heaters [extracted from AD 1].

Type	Number	Heater Resistance	Lead resistance	Power	Max Voltage	Interface type
Heat Switch	2	402 Ω	≤ 100 Ω	0 to 1mW	15 V	2x2-wire

Table 8 Heat Switch heater specification

3.3.2 SPHSheat test results

The following graphs show the transfer curves, the linearity of the current production, and the linearity of the voltage housekeeping measurements.

3.3.2.1 DAC to current transfer curve: full range

Figure 8 shows an overview of the current variation obtained when ramping the DAC through the full [0..4095] range.

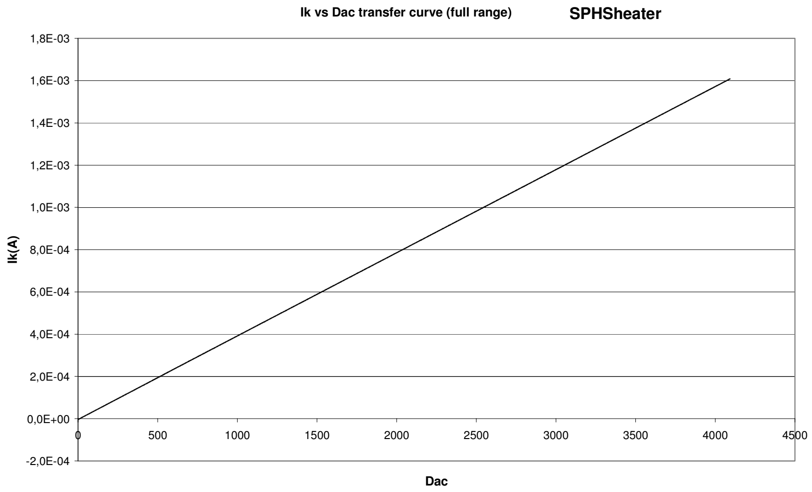


Figure 8 SPHS heater: DAC to current transfer curve (full range)

3.3.2.2 DAC to current linearity

The parameters of the linear transfer function where obtained by linear regression, after discarding the measurement data corresponding to the current extinction area.

Table 9 shows the linear fit results, as provided by the Microsoft Excel regression macro (Analysis Of Variance method).

Regression Statistics	
Multiple R	9.9999951E-01
R Square	9.9999901E-01
Adjusted R Square	9.9999901E-01
Standard Error	4.6172E-07
Observations	4086

	Coefficients	*Standard Error*
Intercept (p0)	-2.05E-06	1.45E-08
Slope (p1)	3.9353E-07	6.1E-12

Table 9 SPHS heater: DAC to current linear fit results

The predicted current is I_{pred} (A) = p0 + p1*DAC.

The circuit shows good linearity, as shown by the RSquare parameter (fraction of variance explained by the linear dependence) which approaches 1 closely. The residual RMS deviation from the fit (standard error) is less than 470 nA. The corresponding residual distribution is shown in Figure 9 , which suggests an integral non linearity effect of ~1/1000 of full range. The peak-to-peak residual error for this particular circuit is contained in a ±2 µA interval (~±5 DAC LSB steps).

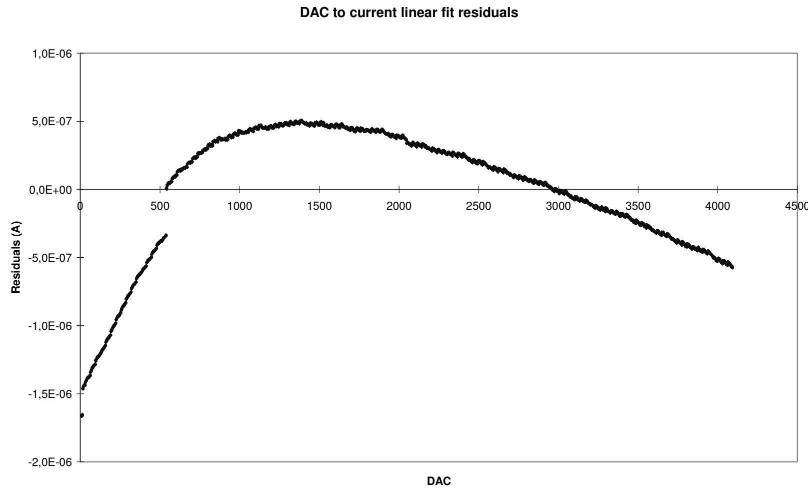


Figure 9 SPHS heater: DAC to current linear fit residuals

3.3.2.3 Voltage measurement

The linear parameters of the ADCv voltage measurement, as a function of the actual voltage V_L across the load, are summarised in Table 10 .

Regression Statistics	
Multiple R	9.9999997E-01
R Square	9.9999994E-01
Adjusted R Square	9.9999994E-01
Standard Error	1.67145759
Observations	4086

	Coefficients	*Standard Error*
Intercept (p0)	-5.945	0.052
Slope (p1)	39315.8	0.14

Table 10 SPHS heater: Voltage to ADCv linear fit results

The predicted ADCv value corresponding to a voltage V_L across the R=405.02 Ω load is:

ADCv = round(p0 + p1* V_L) *[V_L expressed in V].*

The ADCstep voltage equivalent is 25.4 µV (1/p1). The observed residual deviation is 1.67 ADCstep RMS (less than ±4 ADCstep peak-peak) over the full DAC range.

Figure 10 shows the residuals of the linear fit in ADC steps.

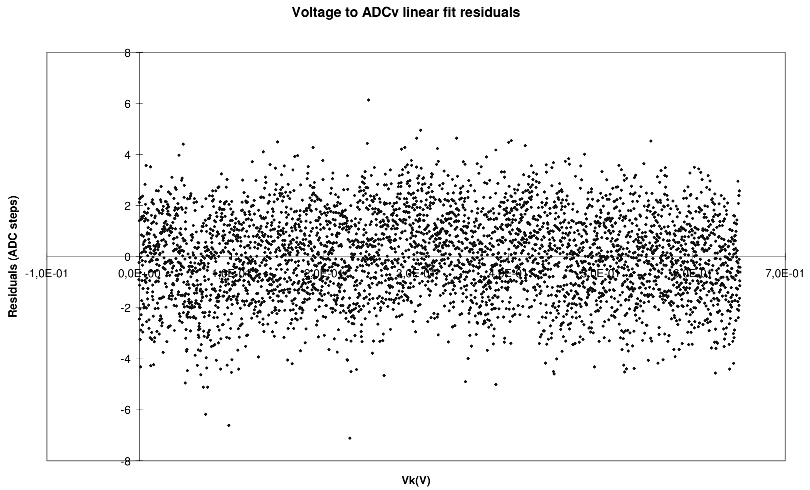


Figure 10 SPHS heater: Voltage to ADCv linear fit residuals

3.3.3 EVHSheat test results

The following graphs show the transfer curves, the linearity of the current production, and the linearity of the voltage housekeeping measurements.

3.3.3.1 DAC to current transfer curve: full range

Figure 11 shows an overview of the current variation obtained when ramping the DAC through the full [0..4095] range.

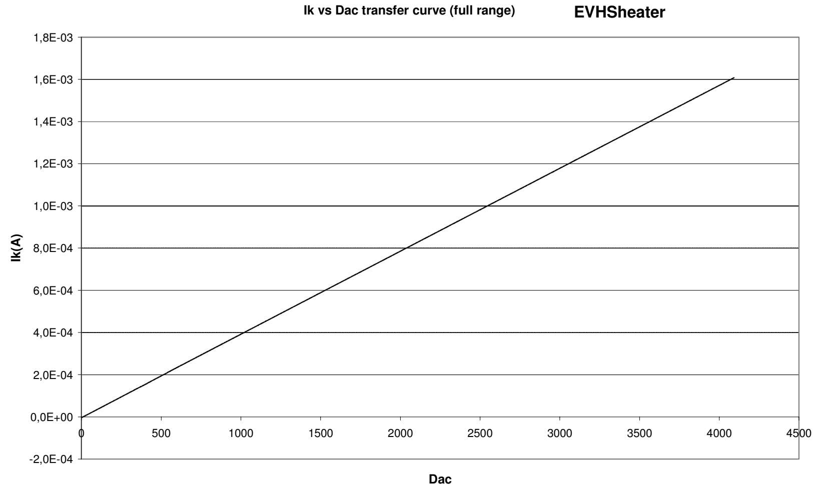


Figure 11 EVHS heater: DAC to current transfer curve (full range)

3.3.3.2 DAC to current linearity

The parameters of the linear transfer function where obtained by linear regression, after discarding the measurement data corresponding to the current extinction area.

Table 11 shows the linear fit results, as provided by the Microsoft Excel regression macro (Analysis Of Variance method).

Regression Statistics	
Multiple R	9.999991E-01
R Square	9.999982E-01
Adjusted R Square	9.999982E-01
Standard Error	6.1892E-07
Observations	4086

	Coefficients	*Standard Error*
Intercept (p0)	-2.44E-06	1.9E-08
Slope (p1)	3.9357E-07	8.2E-12

Table 11 EVHS heater: DAC to current linear fit results

The predicted current is I_{pred} (A) = p0 + p1*DAC.

The circuit shows good linearity, as shown by the RSquare parameter (fraction of variance explained by the linear dependence) which approaches 1 closely. The residual RMS deviation from the fit (standard error) is less than 618 nA. The corresponding residual distribution is shown in Figure 12 , which suggests an integral non linearity effect of ~1/1000 of full range. The peak-to-peak residual error for this particular circuit is contained in a ±1.6 µA interval (~±4 DAC LSB steps).

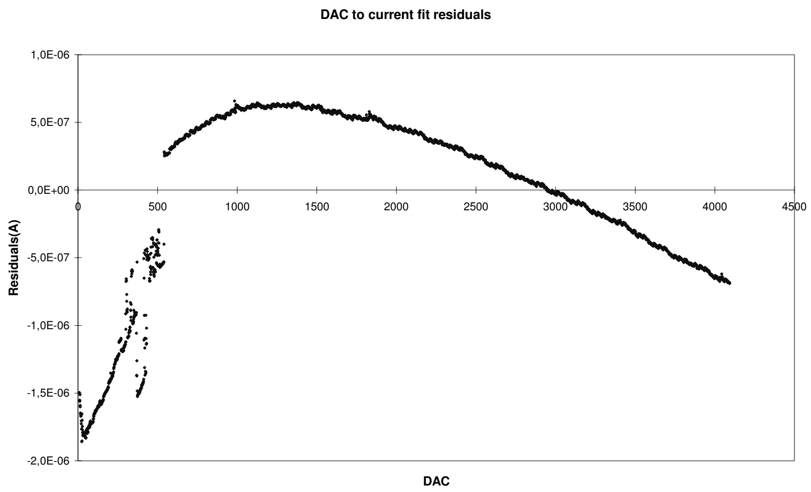


Figure 12 EVHS heater: DAC to current linear fit residuals

3.3.3.3 Voltage measurement

The linear parameters of the ADCv voltage measurement, as a function of the actual voltage V_L across the load, are summarised in Table 10 .

Regression Statistics	
Multiple R	9.9999997E-01
R Square	9.9999994E-01
Adjusted R Square	9.9999994E-01
Standard Error	1.78158433
Observations	4086

	Coefficients	*Standard Error*
Intercept (p0)	-4.94	0.056
Slope (p1)	39323.4	0.15

Table 12 EVHS heater: Voltage to ADCv linear fit results

The predicted ADCv value corresponding to a voltage V_L across the R=405.02 Ω load is:

$$ADCv = round(p0 + p1^* V_L) \qquad [V_L \text{ expressed in V}].$$

The ADCstep voltage equivalent is 25.4 µV (1/p1). The observed residual deviation is 1.67 ADCstep RMS (less than ±4 ADCstep peak-peak) over the full DAC range.

Figure 10 shows the residuals of the linear fit in ADC steps.

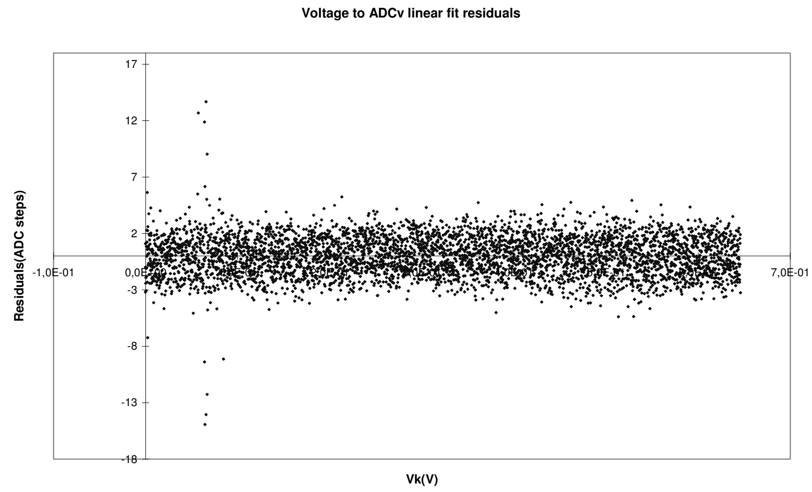


Figure 13 EVHS heater: Voltage to ADCv linear fit residuals

3.4 TCheater

3.4.1 Specification (reminder)

The following table recalls the requirement for the TC low power heater [extracted from AD 1].

Type	Number	Heater resistance	Lead resistance	Power	Max. Voltage	Interface type
TC Heater	1	6 kΩ	≤ 1 kΩ	300mV/50uA		4-wire

Table 13 TC Heater specification

3.4.2 TCheater test results

The following graphs show the transfer curves, the linearity of the current production, and the linearity of the voltage housekeeping measurements.

3.4.2.1 DAC to current transfer curve: full range

Figure 14 shows an overview of the current variation obtained when ramping the DAC through the full [0..4095] range.

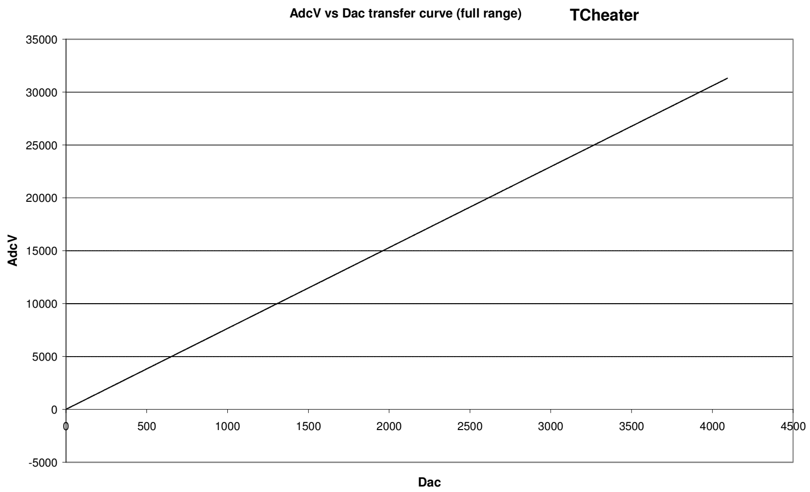


Figure 14 TC heater: DAC to current transfer curve (full range)

3.4.2.2 DAC to current linearity

The parameters of the linear transfer function where obtained by linear regression, after discarding the measurement data corresponding to the current extinction area. Table 14 shows the linear fit results, as provided by the Microsoft Excel regression macro (Analysis Of Variance method).

Regression Statistics	
Multiple R	9.999999992E-01
R Square	9.999999983E-01
Adjusted R Square	9.999999983E-01
Standard Error	5.91227E-10
Observations	4086

	Coefficients	*Standard Error*
Intercept (p0)	-7.09E-09	1.9E-11
Slope (p1)	1.216607E-08	7.8E-15

Table 14 TC heater: DAC to current linear fit results

The predicted current is I_{pred} (A) = p0 + p1*DAC.

The circuit shows excellent linearity, as shown by the RSquare parameter (fraction of variance explained by the linear dependence) which approaches 1 very closely. The residual RMS deviation from the fit (standard error) is less than 600 pA. The corresponding residual distribution is shown in Figure 15 , which shows that most of the variability is certainly due to the structural non linearity in the DAC circuit internals. The peak-to-peak residual error for this particular circuit is contained in a ±3 nA interval (~0.4 DAC LSB step).

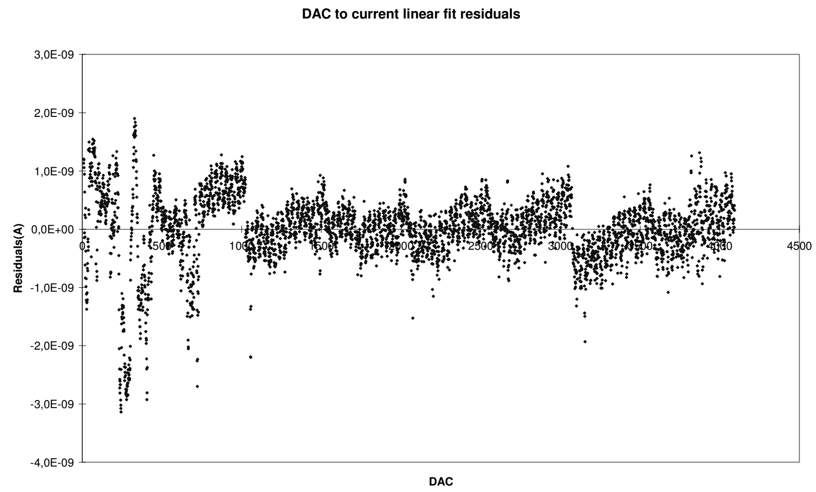


Figure 15 TC heater: DAC to current linear fit residuals

3.4.2.3 Voltage measurement

The linear parameters of the ADCv voltage measurement, as a function of the actual voltage V_L across the load, are summarised in Table 15 .

Regression Statistics	
Multiple R	9.9999995E-01
R Square	9.9999989E-01
Adjusted R Square	9.9999989E-01
Standard Error	2.94340076
Observations	4086

	Coefficients	*Standard Error*
Intercept (p0)	4.70	0.092
Slope (p1)	104810.2	0.54

Table 15 TC heater: Voltage to ADCv linear fit results

The predicted ADCv value corresponding to a voltage V_L across the R=5.99 KΩ load is:

ADCv = round(p0 + p1* V_L) *[V_L expressed in V].*

The ADCstep voltage equivalent is 9.54μV (1/p1). The observed residual deviation is 2.94 ADCstep RMS (less than ±6 ADCstep peak-peak) over the full DAC range.

Figure 16 shows the residuals of the linear fit in ADC steps.

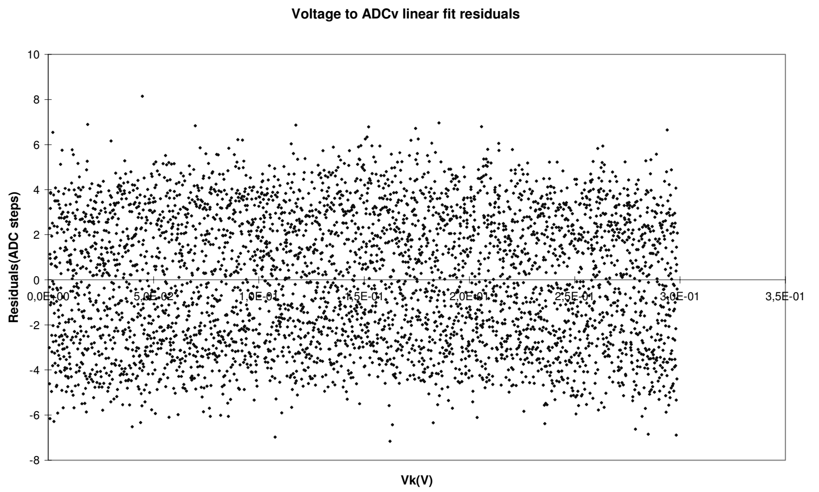


Figure 16 TCheater: Voltage to ADCv linear fit residuals

3.5 PhCal calibrator

3.5.1 Specification (reminder)

The following table recalls the requirements for the PhCal bias current [extracted from AD 1].

Heater Bias Current Range	0 to 7 mA	in 4096 steps
Maximum dissipated power into heater	10 mW	
Heater Resistance Range	200 to 500 Ω	≤ 100 Ω for lead resistance
Stability / Repeatability	0.5 % or 5 µA	Whichever is greater
Maximum drive voltage	3.9 V	Worst case
Bias waveform	square	Spec. for DPU
Waveform frequency	0 to 5 Hz	Spec. for DPU
Waveform resolution	100 ms	Spec. for DPU
Interface Type	2x2-wire	None connected to ground

Table 16 PhCal calibrator specification

3.5.2 PhCal test results

The following graphs show the transfer curves, the linearity of the current production, and the linearity of the voltage and current housekeeping measurements. Unless otherwise stated, all following measurements are taken at laboratory room temperature (~25 °C).

3.5.2.1 DAC to current transfer curve: full range

Figure 17 shows an overview of the current variation obtained when ramping the DAC through the full [0..4095] range.

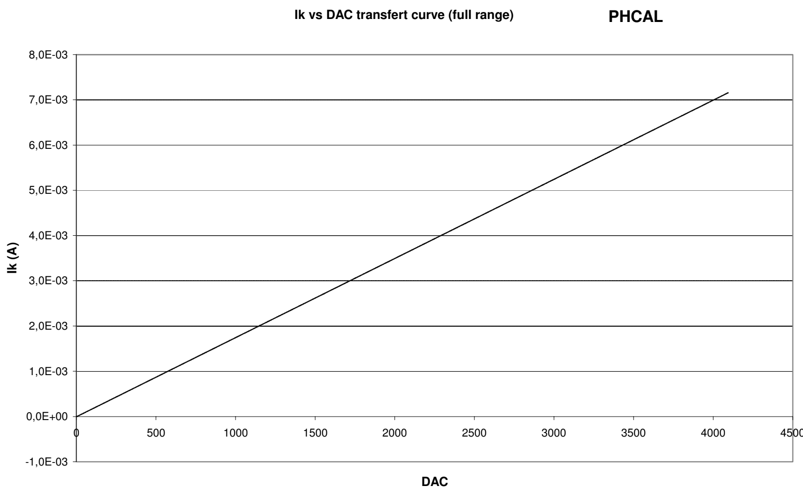


Figure 17 PhCal: DAC to current transfer curve (full range)

3.5.2.2 DAC to current transfer curve : low current

Table 17 shows the measurement figures for the current extinction at low DAC values. An ideal DAC step corresponds to 1.71 µA (7/4096 mA). The circuit cancels current for very low DAC values, providing effective extinction down to few nA, a small fraction of a DAC step. The linear current production starts from DAC value 5.

Dac	AdcI	AdcV	Ik (A)	Vk (A)
0	-7	-2	-5.1191E-09	-3.6277E-06
1	7	-1	-6.4746E-09	-3.6573E-06
2	1	-2	-6.4684E-09	-3.8020E-06
3	1	1	-6.4333E-09	-2.7231E-06
4	3	-1	-6.0784E-09	-1.7240E-06
5	7	-2	1.6412E-06	3.3399E-04
6	11	10	3.4575E-06	7.0858E-04
7	20	19	5.1965E-06	1.0631E-03
8	32	27	6.9516E-06	1.4244E-03
9	32	34	8.6871E-06	1.7790E-03
10	41	43	1.0438E-05	2.1374E-03
11	49	48	1.2167E-05	2.4926E-03
12	54	55	1.3929E-05	2.8523E-03

Table 17 PhCal: current extinction at low DAC values

Figure 18 shows the corresponding enlarged view of the DAC to current transfer curve.

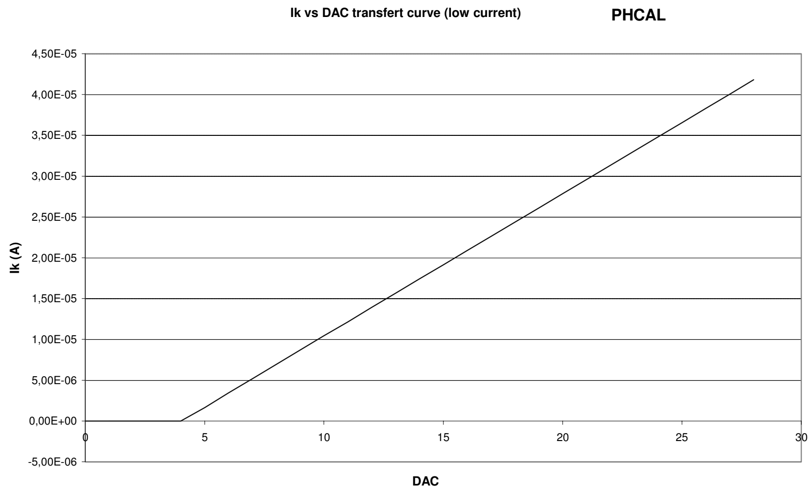


Figure 18 PhCal: DAC to current transfer curve (low current)

3.5.2.3 DAC to current linearity

The parameters of the linear transfer function where obtained by linear regression, after discarding the measurement data corresponding to the current extinction area. Table 18 shows the linear fit results, as provided by the Microsoft Excel regression macro (Analysis Of Variance method).

Regression Statistics	
Multiple R	9.999999997E-01
R Square	9.999999994E-01
Adjusted R Square	9.999999994E-01
Standard Error	4.69E-08
Observations	4092

	Coefficients	*Standard Error*
Intercept (p0)	-7.201E-06	1.5E-09
Slope (p1)	1.749725E-06	6.2E-13

Table 18 PhCal: DAC to current linear fit results

The predicted current is I_{pred} (A) = p0 + p1*DAC.

The circuit shows excellent linearity, as shown by the RSquare parameter (fraction of variance explained by the linear dependence) which approaches 1 very closely. The residual RMS deviation from the fit (standard error) is less than 50 nA. The corresponding residual distribution is shown in Figure 19 , which shows that most of the variability is certainly due to the structural non linearity in the DAC circuit internals. The peak-to-peak residual error for this particular circuit is contained in a ±150 nA interval (~1/10 LSB step), which is surprisingly good when taking into account the DAC circuit specifications and the instruments specifications.

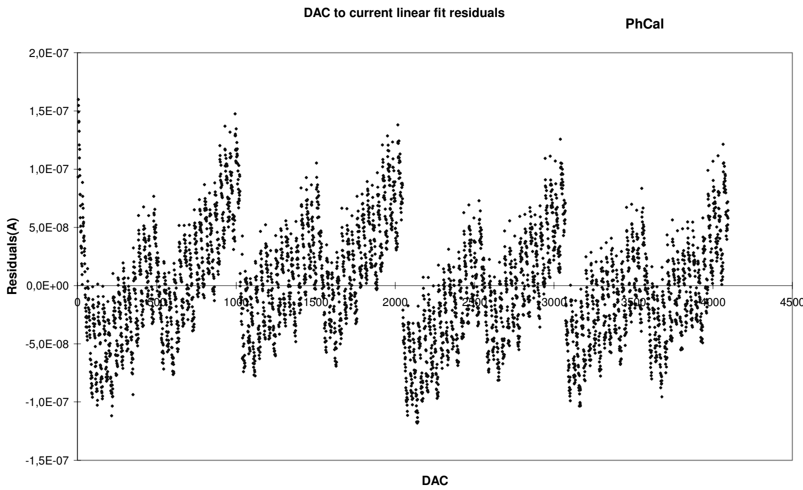


Figure 19 PhCal: DAC to current linear fit residuals

3.5.2.4 Voltage measurement

The linear parameters of the ADCv voltage measurement, as a function of the actual voltage V_L across the load, are summarised in Table 19 .

Regression Statistics	
Multiple R	9.99999992E-01
R Square	9.99999983E-01
Adjusted R Square	9.99999983E-01
Standard Error	1.07865833
Observations	4092

	Coefficients	*Standard Error*
Intercept (p0)	-0.67	0.034
Slope (p1)	19659.35	0.040

Table 19 PhCal: Voltage to ADCv linear fit results

The predicted ADCv value corresponding to a voltage V_L across the R=204.9 Ω load is:

ADCv = round(p0 + p1* V_L) *[V_L expressed in V]*.

The ADCstep voltage equivalent is 50.86 µV (1/p1). The observed residual deviation is 1.07 ADCstep RMS (less than ±4 ADCstep peak-peak) over the full DAC range.

Figure 20 shows the residuals of the linear fit in ADC steps.

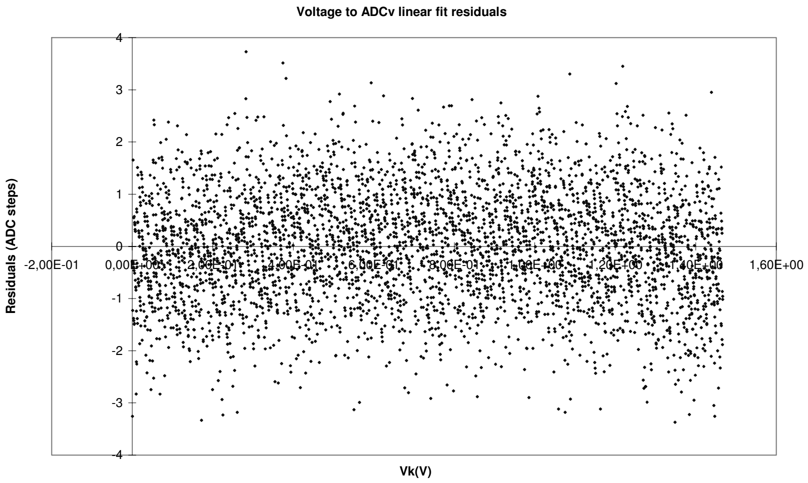


Figure 20 PhCal : Voltage to ADCv linear fit residuals

3.5.2.5 Current measurement

The linear parameters of the ADCi current measurement, as a function of the actual current I_L across the load, are summarised in Table 20 .

Regression Statistics	
Multiple R	9.9999998E-01
R Square	9.9999997E-01
Adjusted R Square	9.9999997E-01
Standard Error	1.34496072
Observations	4092

	Coefficients	*Standard Error*
Intercept (p0)	-1.17	0.042
Slope (p1)	402798.E+01	10.

Table 20 PhCal: Current to ADCi linear fit results

The predicted ADCi value corresponding to a current I_L across the R=204.9 Ω load is:

ADCi = round(p0 + p1* I_L) *[I_L expressed in A]*.

The ADCstep current equivalent is 248.3 nA (1/p1). The observed residual deviation is 1.34 ADCstep RMS (less than ±6 ADCstep peak-peak) over the full DAC range.

Figure 21 shows the residuals of the linear fit in ADC steps.

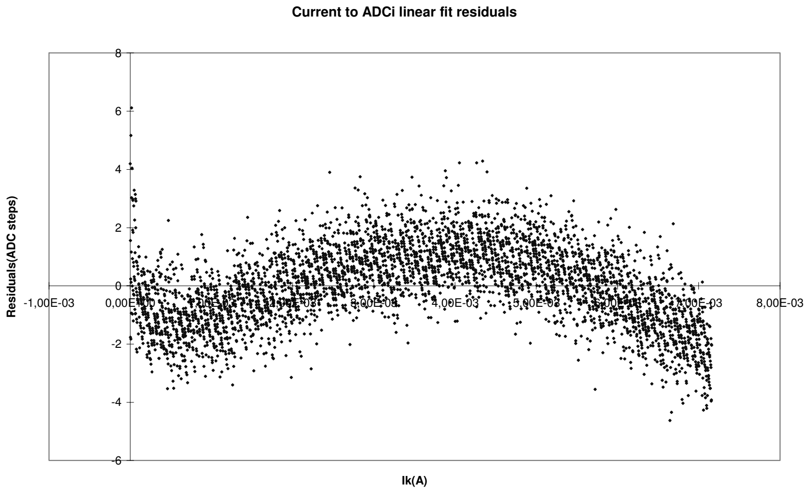


Figure 21 PhCal : Current to ADCi linear fit residuals

3.5.2.6 Variation with temperature

3.5.2.6.1 Initial prototype estimates (reminder)

On the initial prototype circuit, the current variation with temperature was derived from measurements at 0℃, 25℃ and 50℃. The measured variation was 25µA/50℃@9mA, corresponding to a relative dependence of less than 60 ppm/℃. The specification for relative stability asks for 5.E-03/h, with a maximum temperature drift of 3K/h. As a result, and without correction, the temperature variation will account for less than 4% of the total stability budget (180 ppm of the requested 5000 ppm/h).

3.5.2.6.2 Stability versus temperature

The stability of the QM1 PhCal circuit was surveyed at room temperature on a dedicated night run showing a 4℃ variation. The temperature was monitored by the AD590 probes placed on the Temp board (TcuT probe) and CChkIf board (CcuT probe). The result is shown in Figure 22 . The TcuT and CcuT probe ADC values (right axis) reflect the 4℃ variation (26 ADC steps, 6.55 ADC steps/℃ conversion, see §6.1) over the [t1..t2] time interval (8:20 min). The ADCv and ADCi monitoring circuits (left axis) show a 3 (resp. 2) ADC step variation (less than 0.1% over 4℃). The requirement asks for 0.5% over 3℃.

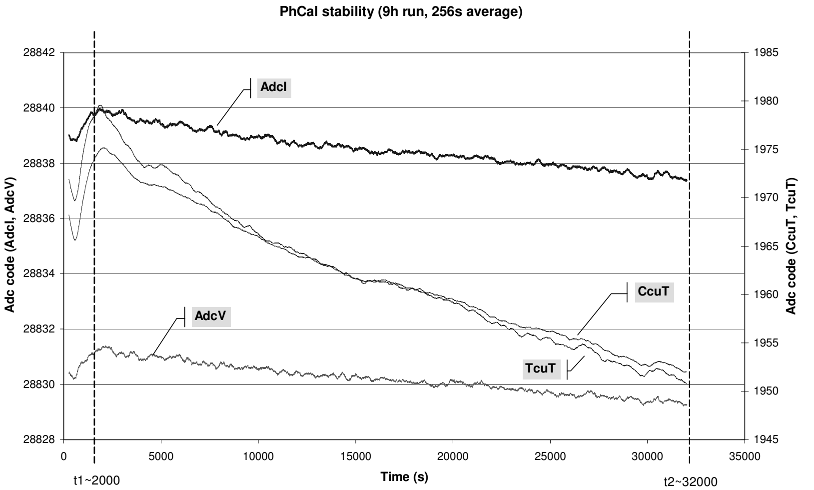


Figure 22 PhCal stability survey

This stability check could not be repeated for all DAC values. However, preliminary prototype tests had shown that the temperature variation is proportional to the DAC value. We can thus expect that the relative stability requirement will still be fulfilled for low DAC values.

3.5.2.6.3 Dynamic properties

The PhCal circuit response to full DAC swing steps (rise: 0→4095, fall: 4095→0) is shown in Figure 23 & Figure 24 .

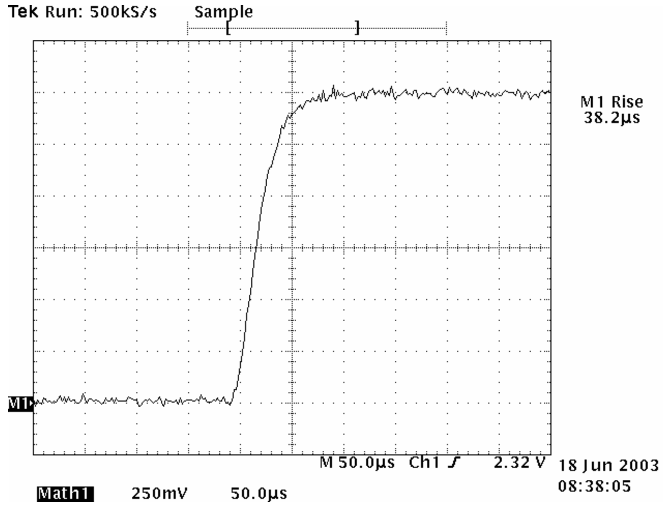


Figure 23 PhCal full DAC step rise time

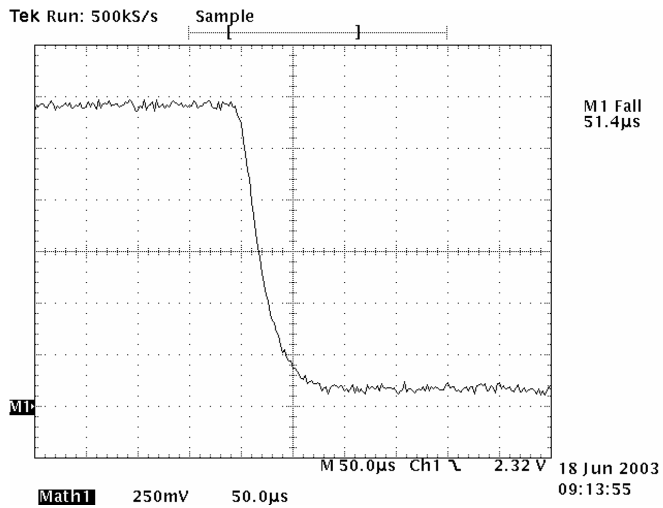


Figure 24 PhCal full DAC step fall time

3.6 SCal2% & SCal4% calibrators

3.6.1 Specification (reminder)

The following table recalls the requirements for the SCal calibrators bias current [extracted from AD 1].

Heater Bias Current Range	0 to 5.5 mA	in 4096 steps
Maximum dissipated power into heater	15 mW	
Heater Resistance Range	500 Ω	≤ 100 Ω for lead resistance
Stability / Repeatability	0.5 % or 5 µA	Whichever is greater
Maximum drive voltage	3.1 V	Worst case
Bias waveform	DC	
Electrical Interface Type	2x2-wire	None connected to ground

Table 21 SCal calibrators specification

3.6.2 Scal2% test results

The following graphs show the transfer curves, the linearity of the current production, and the linearity of the voltage and current housekeeping measurements.

3.6.2.1 DAC to current transfer curve : full range

Figure 25 shows an overview of the current variation obtained when ramping the DAC through the full [0..4095] range.

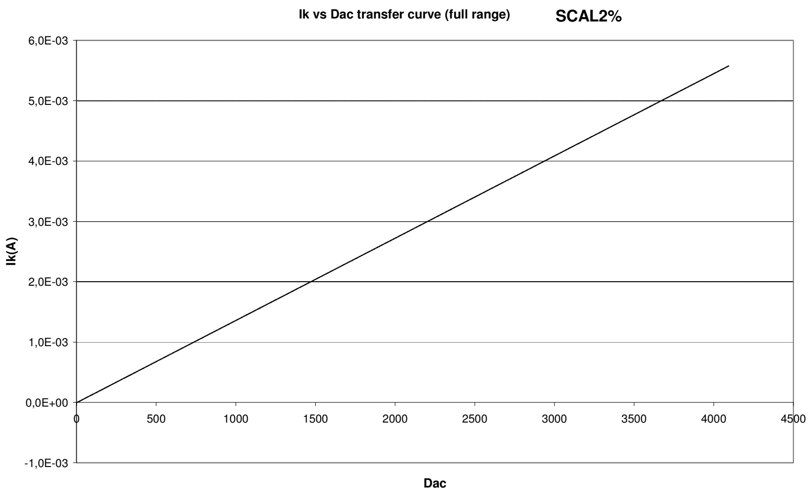


Figure 25 SCAL2%: DAC to current transfer curve (full range)

3.6.2.2 DAC to current transfer curve : low current

Table 22 shows the measurement figures for the current extinction at low DAC values. An ideal DAC step corresponds to 1.34 µA (5.5/4096 mA). The circuit cancels current for very low DAC values, providing effective extinction down to few nA, a small fraction of a DAC step. The linear current production starts from DAC value 5.

Dac	AdcI	AdcV	Ik (A)	Vk (A)
0	4	-2	-7.1950E-09	-5.8516E-06
1	-7	-3	-7.5446E-09	-5.8208E-06
2	4	-3	-7.7385E-09	-7.5889E-06
3	-3	-3	-7.4597E-09	-8.8319E-06
4	1	-3	3.3507E-08	1.5560E-05
5	5	3	1.2940E-06	6.5749E-04
6	19	12	2.7330E-06	1.3916E-03
7	23	19	4.0898E-06	2.0842E-03
8	26	26	5.4726E-06	2.7879E-03
9	35	34	6.8344E-06	3.4822E-03
10	41	41	8.2028E-06	4.1813E-03
11	53	48	9.5628E-06	4.8720E-03
12	60	53	1.0922E-05	5.5681E-03

Table 22 Scal2%: current extinction at low DAC values

Figure 26 shows the corresponding enlarged view of the DAC to current transfer curve.

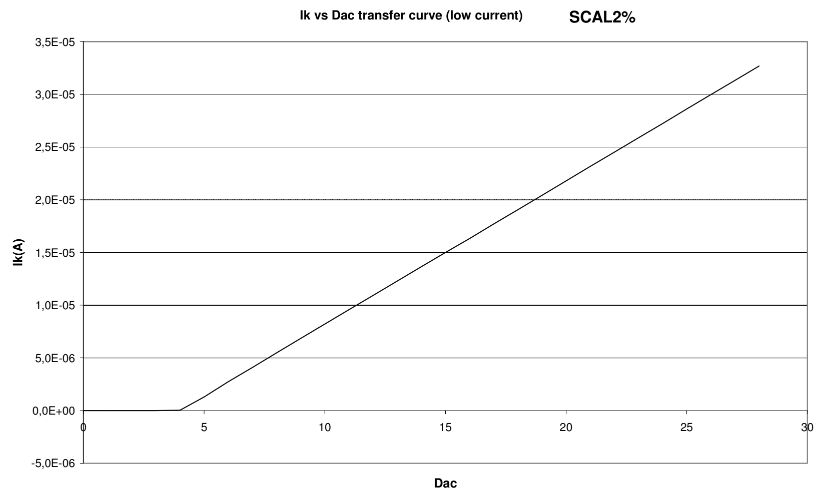


Figure 26 SCAL2% : DAC to current transfer curve (low current)

3.6.2.3 DAC to current linearity

The parameters of the linear transfer function where obtained by linear regression, after discarding the measurement data corresponding to the current extinction area.

Table 23 shows the linear fit results, as provided by the Microsoft Excel regression macro (Analysis Of Variance method).

Regression Statistics	
Multiple R	9.999999996E-01
R Square	9.999999993E-01
Adjusted R Square	9.999999993E-01
Standard Error	4.2195E-08
Observations	4041

	Coefficients	*Standard Error*
Intercept(p1)	-5.476E-06	1.3E-09
Slope(p1)	1.363062E-06	5.7E-13

Table 23 Scal2%: DAC to current linear fit results

The predicted current is I_{pred} (A) = p0 + p1*DAC.

The circuit shows excellent linearity, as shown by the RSquare parameter (fraction of variance explained by the linear dependence) which approaches 1 very closely. The residual RMS deviation from the fit (standard error) is less than 50 nA. The corresponding residual distribution is shown in Figure 27 , which shows that most of the variability is certainly due to the structural non linearity in the DAC circuit internals. The peak-to-peak residual error for this particular circuit is contained in a ±100 nA interval (~±1/10 DAC LSB step), which is surprisingly good (see discussion §3.5.2.3).

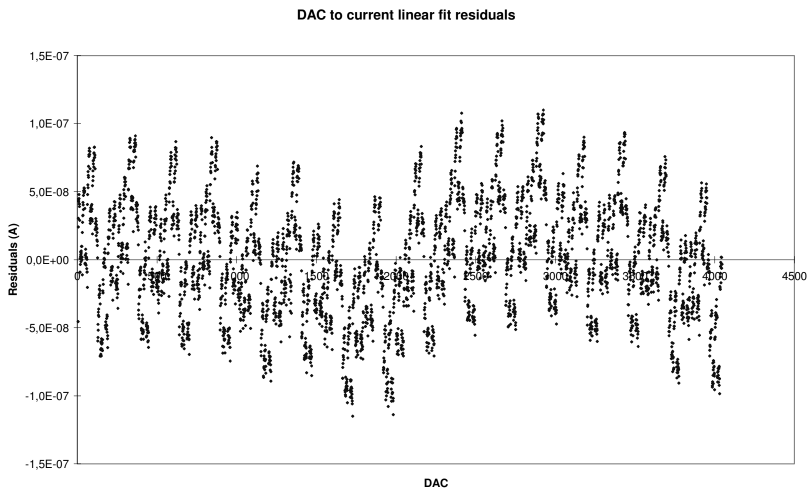


Figure 27 SCAL2% : DAC to curent linear fit residuals

3.6.2.4 Voltage measurement

The linear parameters of the ADCv voltage measurement, as a function of the actual voltage V_L across the load, are summarised in Table 24 .

Regression Statistics		
Multiple R	9.99999991E-01	
R Square	9.99999983E-01	
Adjusted R Square	9.99999983E-01	
Standard Error	1.07869672	
Observations	4092	
	Coefficients	*Standard Error*
Intercept (p0)	-1.62	0.034
Slope (p1)	10015.42	0.021

Table 24 Scal2%: Voltage to ADCv linear fit results

The predicted ADCv value corresponding to a voltage V_L across the R=510 Ω load is:

ADCv = round(p0 + p1* V_L) *[V_L expressed in V].*

The ADCstep voltage equivalent is 99.85 µV (1/p1). The observed residual deviation is 1.07 ADCstep RMS (less than ±4 ADCstep peak-peak) over the full DAC range.

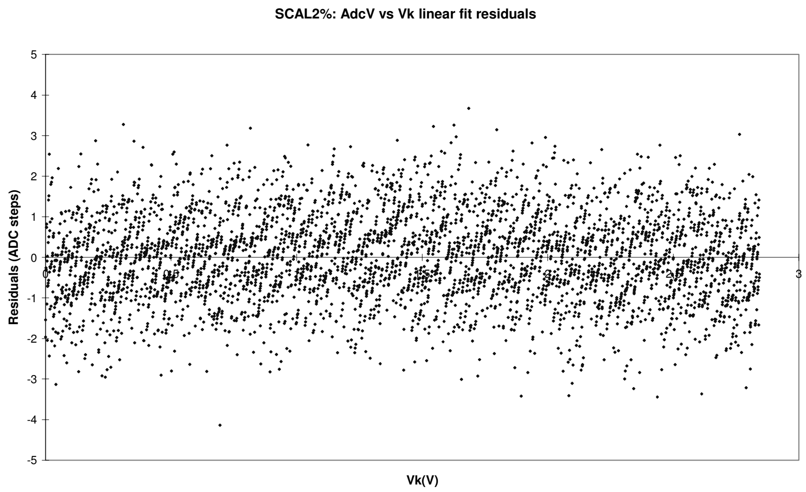


Figure 28 SCAL2% : Voltage to ADCv linear fit residuals

3.6.2.5 Current measurement

The linear parameters of the ADCi current measurement, as a function of the actual current I_L across the load, are summarised in Table 25 .

Regression Statistics		
Multiple R	9.9999998E-01	
R Square	9.9999996E-01	
Adjusted R Square	9.9999996E-01	
Standard Error	1.64241461	
Observations	4041	
	Coefficients	*Standard Error*
Intercept (p0)	0.81	0.052
Slope (p1)	563018.E+01	16.

Table 25 Scal2%: Current to ADCi linear fit results

The predicted ADCi value corresponding to a current I_L across the R=204.9 Ω load is:

ADCi= round(p0 + p1* I_L) *[I_L expressed in A].*

The ADCstep current equivalent is 248.3 nA (1/p1). The observed residual deviation is 1.64 ADCstep RMS (less than ±6 ADCstep peak-peak) over the full DAC range.

Figure 29 shows the residuals of the linear fit in ADC steps.

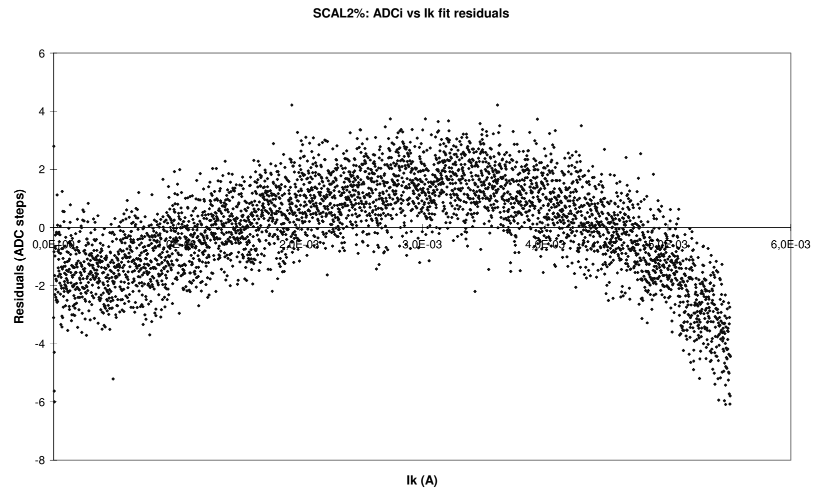


Figure 29 SCAL2% : Current to ADCi linear fit residuals

3.6.3 SCal4% test results

The following graphs show the transfer curves, the linearity of the current production, and the linearity of the voltage and current housekeeping measurements.

3.6.3.1 DAC to current transfer curve : full range

Figure 30 shows an overview of the current variation obtained when ramping the DAC through the full [0..4095] range.

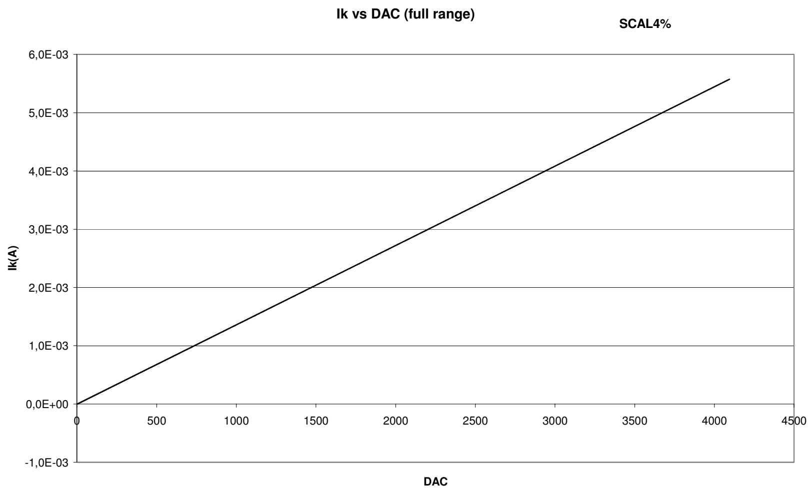


Figure 30 SCAL4% : DAC to current transfer curve (full range)

3.6.3.2 DAC to current transfer curve : low current

Table 26 shows the measurement figures for the current extinction at low DAC values. An ideal DAC step corresponds to 1.34 µA (5.5/4096 mA). The circuit cancels current for very low DAC values, providing effective extinction down to few nA, a small fraction of a DAC step. The linear current production starts from DAC value 5.

Dac	AdcI	AdcV	Ik (A)	Vk (A)
0	-5	-2	-1.0211E-08	-7.2324E-06
1	3	0	-7.1537E-09	-8.0128E-06
2	4	-2	-8.3277E-09	-8.7796E-06
3	1	-3	-9.7322E-09	-8.3979E-06
4	0	-2	-8.2603E-09	-8.2988E-06
5	5	-1	1.0794E-06	5.4658E-04
6	9	10	2.5346E-06	1.2877E-03
7	19	17	3.8887E-06	1.9780E-03
8	24	25	5.2444E-06	2.6694E-03
9	33	34	6.6030E-06	3.3607E-03
10	45	40	7.9716E-06	4.0605E-03
11	51	46	9.3302E-06	4.7516E-03
12	57	54	1.0703E-05	5.4508E-03

Table 26 Scal4%: current extinction at low DAC values

Figure 31 shows the corresponding enlarged view of the DAC to current transfer curve.

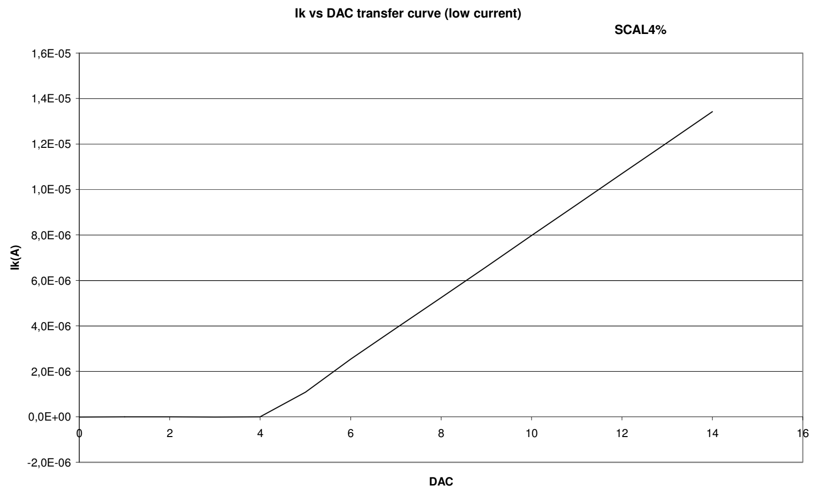


Figure 31 SCAL4% : DAC to current transfer curve (low current)

3.6.3.3 DAC to current linearity

The parameters of the linear transfer function where obtained by linear regression, after discarding the measurement data corresponding to the current extinction area.

Table 27 shows the linear fit results, as provided by the Microsoft Excel regression macro (Analysis Of Variance method).

Regression Statistics	
Multiple R	9.999999997E-01
R Square	9.999999994E-01
Adjusted R Square	9.999999994E-01
Standard Error	3.98787E-08
Observations	4088

	Coefficients	*Standard Error*
Intercept (p0)	-5.667E-06	1.3E-09
Slope (p1)	1.362775E-06	5.3E-13

Table 27 Scal4%: DAC to current linear fit results

The predicted current is I_{pred} (A) = p0 + p1*DAC.

The circuit shows excellent linearity, as shown by the RSquare parameter (fraction of variance explained by the linear dependence) which approaches 1 very closely. The residual RMS deviation from the fit (standard error) is less than 40 nA. The corresponding residual distribution is shown in Figure 32 , which shows that most of the variability is certainly due to the structural non linearity in the DAC circuit internals. The peak-to-peak residual error for this particular circuit is contained in a ±100 nA interval (~±1/10 DAC LSB step), which is surprisingly good (see discussion §3.5.2.3).

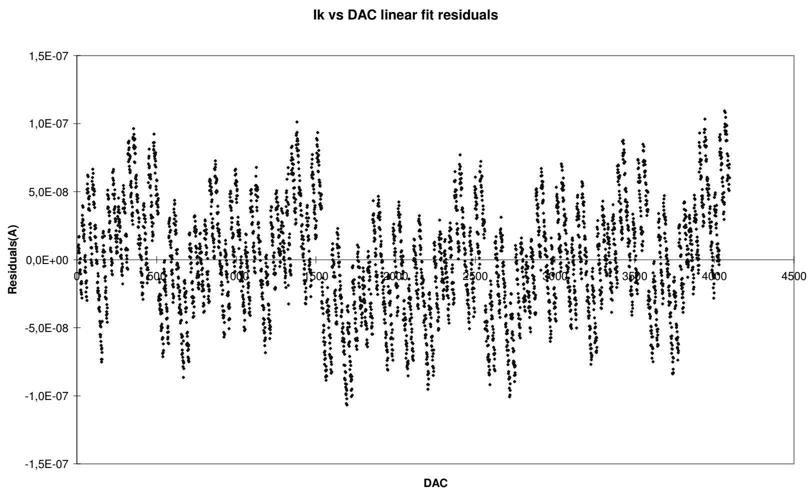


Figure 32 SCAL4% : DAC to current linear fit residuals

3.6.3.4 Voltage measurement

The linear parameters of the ADCv voltage measurement, as a function of the actual voltage V_L across the load, are summarised in Table 28 .

Regression Statistics	
Multiple R	9.99999991E-01
R Square	9.99999983E-01
Adjusted R Square	9.99999983E-01
Standard Error	1.072523659
Observations	4088

	Coefficients	*Standard Error*
Intercept(p0)	-1.25	0.034
Slope(p1)	10005.7	0.021

Table 28 Scal4%: Voltage to ADCv linear fit results

The predicted ADCv value corresponding to a voltage V_L across the R=510 Ω load is:

ADCv = round(p0 + p1* V_L) *[V_L expressed in V].*

The ADCstep voltage equivalent is 99.94 µV (1/p1). The observed residual deviation is 1.07 ADCstep RMS (less than ±4 ADCstep peak-peak) over the full DAC range.

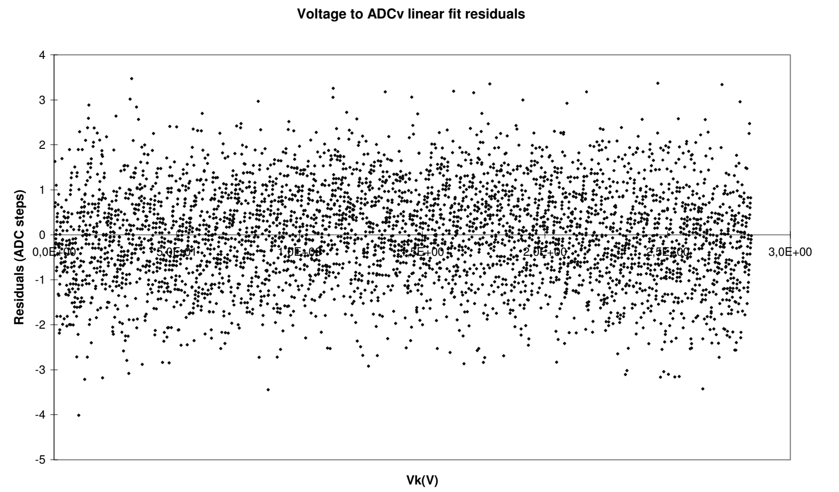


Figure 33 SCAL4% : Voltage to ADCv linear fit residuals

3.6.3.5 Current measurement

The linear parameters of the ADCi current measurement, as a function of the actual current I_L across the load, are summarised in Table 29 .

Regression Statistics	
Multiple R	9.9999998E-01
R Square	9.9999997E-01
Adjusted R Square	9.9999997E-01
Standard Error	1.545779491
Observations	4088

	Coefficients	*Standard Error*
Intercept (p0)	0.19	0.048
Slope(p1)	562795.E+01	15.

Table 29 Scal4%: Current to ADCi linear fit results

The predicted ADCi value corresponding to a current I_L across the R=509.7 Ω load is:

ADCi = round(p0 + p1* I_L) *[I_L expressed in A].*

The ADCstep current equivalent is 177.68 nA (1/p1). The observed residual deviation is 1.55 ADCstep RMS (less than ±6 ADCstep peak-peak) over the full DAC range.

Figure 34 shows the residuals of the linear fit in ADC steps.

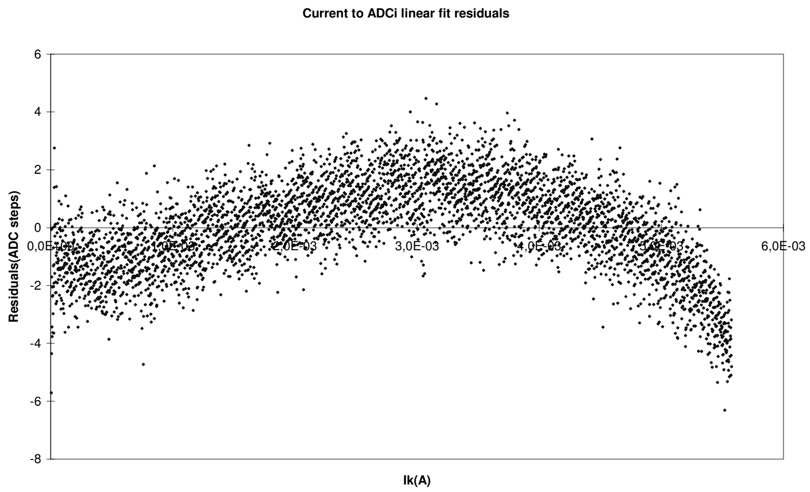


Figure 34 SCAL4% : Current to ADCi linear fit residuals

4 FPUTemp tests

This section gives the test conditions and results for the FPUTemp analogue channels.

4.1 FPUTemp test configuration

The same test configuration is used for the 16 FPUTemp channels (FPUTemp1,-2, …, -16). The channel under test is connected to a variable load resistor R_L while the other channels are connected to a default resistor load. Alternately, the channels may be simply isolated from their load. The connection/isolation is implemented with PhotoMos relays (NAIS AQY221N2). The variable resistor load is implemented by a digital potentiometer (Analog Devices AD8403). The actual current (I_L) and voltage (V_L) across the load are measured by external high-precision (GPIB-driven) instruments (Keithley model 6485 picoammeter and Keithley model 2750 multimeter), which give the I_K and V_K estimates. A conceptual view of the setup is shown in Figure 35 .

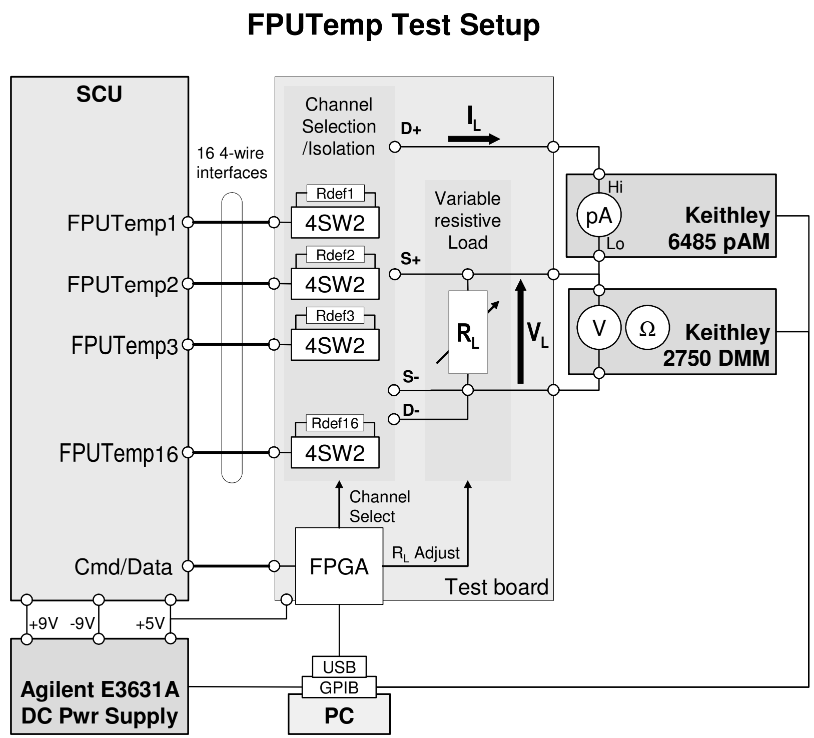


Figure 35 Test configuration for FPUTemp channels

Each 4SW2 module is an arrangement of 8 PhotoMos relay switches that can either isolate the 4-wire interface of the corresponding channel, connect it to a default load (Rdef), or connect it to the measurement section. For each measurement point, the SCU is first isolated from the measurement section by a PC command. The required R_L value is then installed by another PC command. At this stage, the 2750 DMM is placed in its ohmmeter configuration, interrogated to obtain a measurement of R_L (R_K estimate), and restored to its voltmeter configuration. The SCU channel under test is then connected to the load. After a programmable settling time, the instruments are interrogated to obtain the I_K and V_K estimates, and the SCU is interrogated by a GetParameter primitive to obtain the ADCi image of the load current and the usual ancillary data (temperature board, etc.).

4.2 FPUTemp channel characteristics

Table 30 recalls the the FPUTemp channel names, aliases and temperature range specifications. Using a typical CERNOX probe calibration table, the corresponding load resistance range [Rmin..Rmax] was derived. The resolution (Res) and accuracy (Acc) requirements are also indicated.

Name	Alias	Tmin (K)	Tmax (K)	Rmin (Ohm)	Rmax (Ohm)	Gain (Y2Vadc)	Res (mK)	Acc (mK)
T_CPHP	FpuTemp01	1.5	50.	127	1700	549	500.	1000.
T_CPHS	FpuTemp02	1.5	25.	186	1700	825	500.	1000.
T_CEHS	FpuTemp03	1.5	25.	186	1700	825	500.	1000.
T_CSHT	FpuTemp04	1.5	10.	316	1700	1300	500.	1000.
T_SOB	FpuTemp05	3.	300.	38	779	191	10.	10.
T_SLO	FpuTemp06	1.	10.	316	2900	1300	2.	2.
T_PLO	FpuTemp07	1.	10.	316	2900	1300	2.	2.
T_SUB	FpuTemp08	3.	100.	82	779	324	25.	25.
T_BAF	FpuTemp09	3.	100.	82	779	324	10.	10.
T_BSMS	FpuTemp10	3.	100.	95	779	442	5.	5.
T_SCL2	FpuTemp11	10.	80	95	316	442	5.	5.
T_SCL4	FpuTemp12	10.	80	95	316	442	5.	5.
T_SCST	FpuTemp13	1.	50.	127	2900	549	10.	10.
T_FTSS	FpuTemp14	3.	100.	82	779	324	25.	50.
T_FTSM	FpuTemp15	3.	20.	215	779	1000	10.	10.
T_BSMM	FpuTemp16	3.	20.	215	779	1000	10.	10.

Table 30 FPUTemp channel characteristics

The FPUTemp channel is a voltage-controlled variable current source. When the load resistor changes, the current is modified in order to produce a fixed voltage bias V_L=10 mV across the load. The differential voltage across the sense wires of the 4-wire interface is continuously monitored and compared to an internal 10 mV reference voltage to produce the error signal of the feedback loop. The corresponding equilibrium load current $I_L= V_L/R_L= V_L Y_L$ is converted to voltage and measured with an ADC. The resulting ADCi measurement is thus proportional to the load admittance Y_L. The Gain column indicates the ideal transfer factor used in the Y_L to voltage conversion. This factor was optimized for each channel to fulfill the resolution specification without saturating the ADC input range.

4.3 FPUTemp channel tests

4.3.1 Method

The linearity of the Y_L to ADCi transfer function is first assessed for each channel (linear regression, analysis of variance method). For each measurement point, the residual error from the fit (expressed in ADC step units) is then translated to temperature equivalents (expressed in mK), taking the derivative of the (typical) CERNOX Y-to-T transfer curve at this particular point.

4.3.2 Analysis

Although the conceptual Y_L to ADCi transfer function is linear, the actual FPUTemp channels show a non linearity effect for low load resistance values. This non linearity results from common mode and offset errors that build up in the differential voltage sensing circuit when the load current increases. This effect specially affects the channels for which the temperature range extends to high values, and is visible in the high temperature (low CERNOX resistance) side of the range. For most channels, the response cannot be given as a simple 2-parameter linear function because the systematic error on the high temperature side of the channel range exceeds the accuracy requirement.

4.3.3 Linear sub-range

For any particular FPUTemp channel, it is understood that the important usage area is the low temperature (high CERNOX resistance) side of the range. We felt useful to understand the low-temperature fraction of the usage range where the channel response can be expressed as a linear function and still fulfill the accuracy requirement.

For each channel, we restricted the resistance range towards the low temperature side until we found the required accuracy. The resulting acceptance sub-range is given in Table 31 .

Name	Alias	R-SubRange (%)	Rmin (Ω)	Rmin SubRange (Ω)	Rmax (Ω)	Tmin (K)	Tmax SubRange (K)	Tmax (K)	Acc (mK)
T_CPHP	FpuTemp01	90.	127	284	1700	1.5	11.	50.	1000.
T_CPHS	FpuTemp02	90.	186	337	1700	1.5	8.	25.	1000.
T_CEHS	FpuTemp03	90.	186	337	1700	1.5	8.	25.	1000.
T_CSHT	FpuTemp04	90.	316	454	1700	1.5	5.5	10.	1000.
T_SOB	FpuTemp05	40.	38	482	779	3.	5.0	300.	10.
T_SLO	FpuTemp06	25.	316	2254	2900	1.	1.2	10.	2.
T_PLO	FpuTemp07	25.	316	2254	2900	1.	1.2.	10.	2.
T_SUB	FpuTemp08	60.	82	361	779	3.	8.	100.	25.
T_BAF	FpuTemp09	50.	82	430	779	3.	6.2	100.	10.
T_BSMS	FpuTemp10	40.	95	505	779	3.	4.6.	100.	5.
T_SCL2	FpuTemp11	40.	95	228	316	10.	17.	80	5.
T_SCL4	FpuTemp12	40.	95	228	316	10.	17.	80	5.
T_SCST	FpuTemp13	70.	127	959	2900	1.	2.4.	50.	10.
T_FTSS	FpuTemp14	70.	82	291	779	3.	11.	100.	50.
T_FTSM	FpuTemp15	70.	215	384	779	3.	7.	20.	10.
T_BSMM	FpuTemp16	70.	215	384	779	3.	7.	20.	10.

Table 31 FPUTemp channel linear sub-ranges

For channels T_SOB, T_SLO, T_PLO, T_SUB, T_BAF, T_BSMS, T_SCST and T_FTSS, which show strong range and/or accuracy requirements, the temperature sub-range linear acceptance fraction is less than 10%.

4.3.4 FpuTemp response

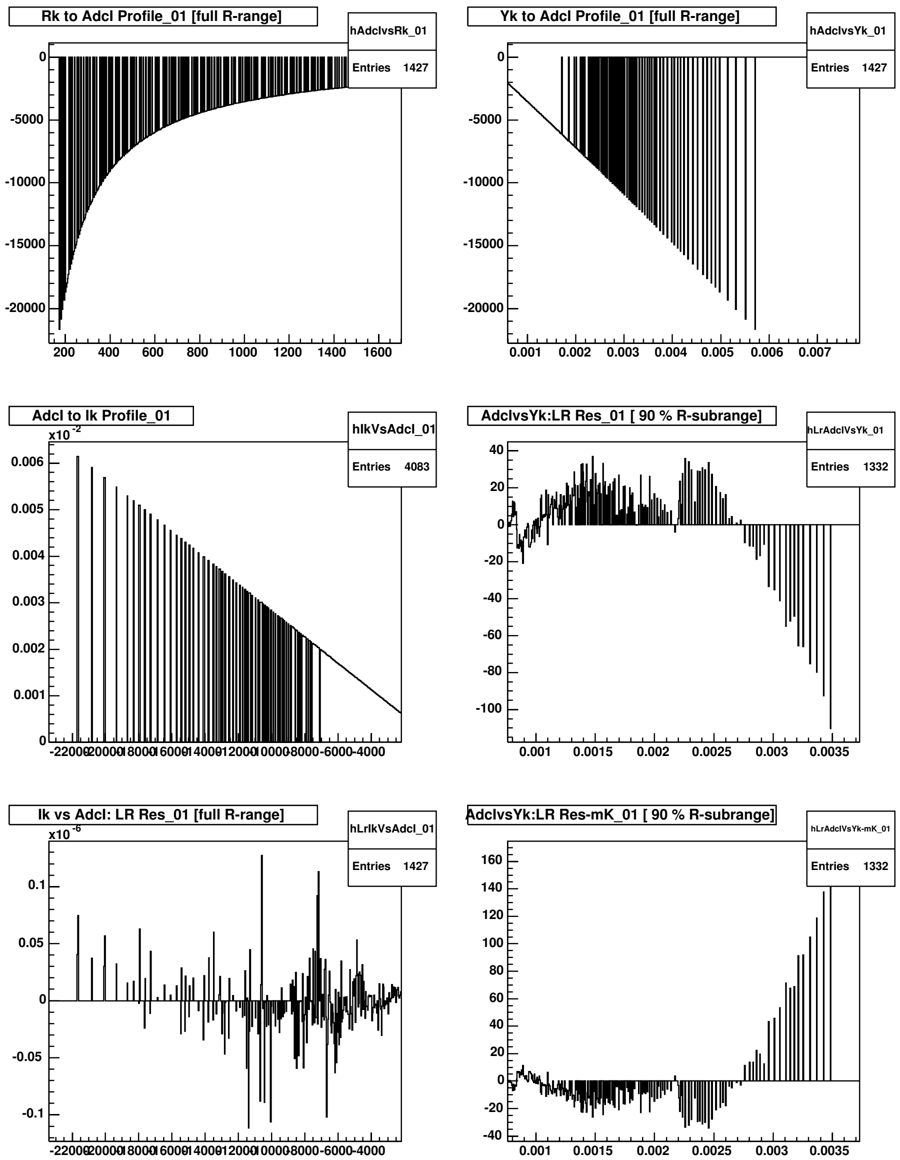
The corresponding full range dependency and sub-range linear fit residue plots are given in the following. The residue plots expressed in mK equivalents are given for reference.

The following plots give, for each channel (nn= 01..16):

- The ADCi = f(Rk) dependency histogram (hAdcIvsRk_nn), obtained when sweeping the load resistance inside the channel [Rmin..Rmax] range (full R-Range);
- The ADCi = f(Yk) dependency histogram (hAdcIvsYk_nn), obtained when sweeping the load resistance inside the channel [Rmin..Rmax] range (full R-range), and the corresponding linear fit residual plots [AdcIvsYk: LR Res_nn (ADC step units), AdcIvsYk: LR Res-mK_nn (mK-equivalent units)], restricted to the channel accuracy subrange;
- The Ik = f(ADCi) dependency histogram (hIkVsAdcI_nn), obtained when varying the load resistance from 160 Ω to 4.5 kΩ (full test range), and the corresponding linear fit residual plot [Ik vs AdcI: LR Res_nn], restricted to the channel full R-Range.

For each FPUTemp channel, the corresponding linear regressions statistics and results are given.

4.3.4.1 *T_CPHP (alias FpuTemp01) plots*



4.3.4.2 T_CPHP (alias FpuTemp01) linear transfer functions

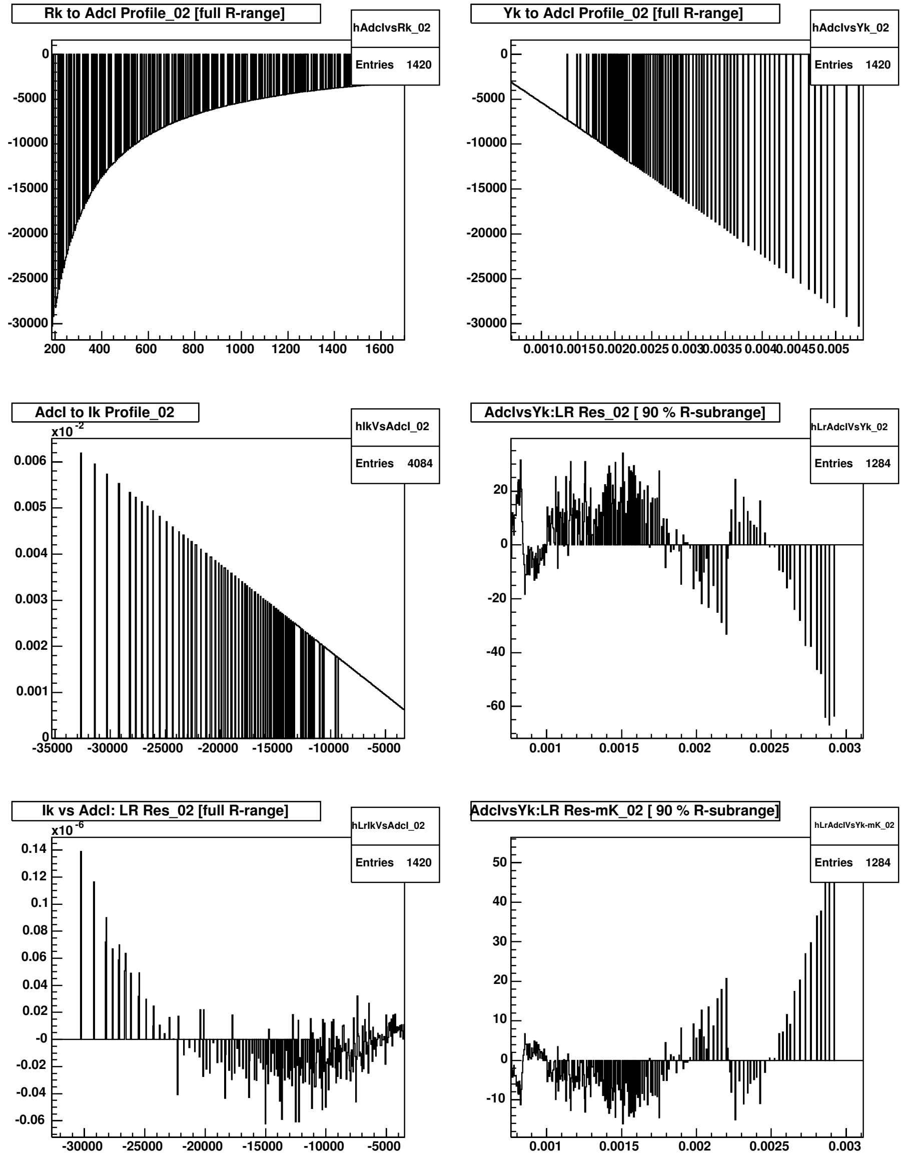
Channel	*T_CPHP [Alias FpuTemp01]*
R-SubRange	90%
Regression mode	LR_AdcIVsYk
X variable	Yk
Y variable	AdcI
Regression Statistics	
R Square	0.999919
Standard Error	2.2500e+001
Standard Error (mK equivalent)	2.2451e+001
Observations	1332

	Coefficients	*Standard Error*
Intercept (P0)	1.3283e+002	1.295e+000
Slope (P1)	-3.6758e+006	9.090e+002

Channel	*T_CPHP [Alias FpuTemp01]*
R-SubRange	90%
Regression mode	LR_IkVsAdcI
X variable	AdcI
Y variable	Ik
Regression Statistics	
R Square	0.999990
Standard Error	3.5176e-008
Observations	1427

	Coefficients	*Standard Error*
Intercept (P0)	-1.8827e-008	1.575e-009
Slope (P1)	-2.8357e-009	2.414e-013

4.3.4.3 T_CPHS (alias FpuTemp02) plots



4.3.4.4 T_CPHS (alias FpuTemp02) linear transfer functions

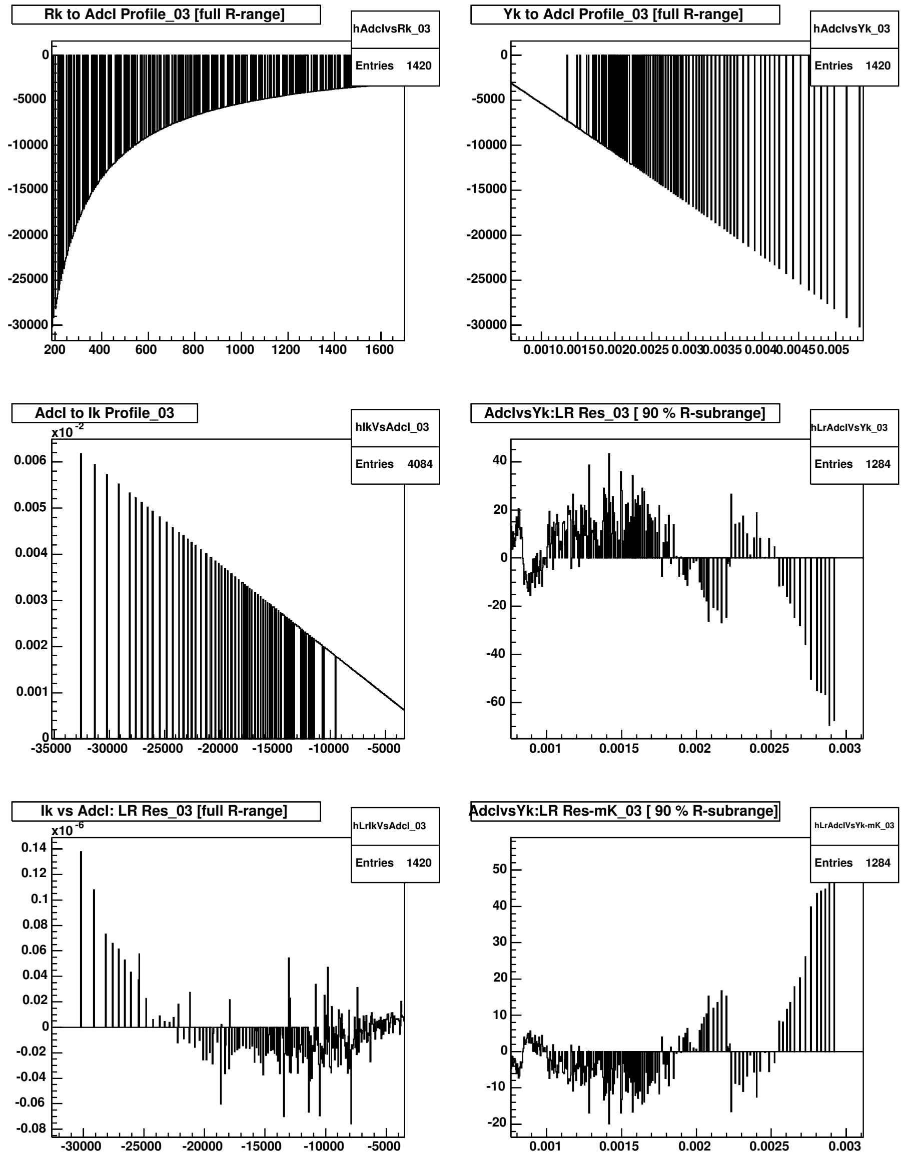
Channel	*T_CPHS [Alias FpuTemp02]*
R-SubRange	90%
Regression mode	LR_AdcIVsYk
X variable	Yk
Y variable	AdcI
Regression Statistics	
R Square	0.999959
Standard Error	2.0209e+001
Standard Error (mK equivalent)	1.0213e+001
Observations	1284

	Coefficients	*Standard Error*
Intercept (P0)	1.8113e+002	1.292e+000
Slope (P1)	-5.5417e+006	9.853e+002

Channel	*T_CPHS [Alias FpuTemp02]*
R-SubRange	90%
Regression mode	LR_IkVsAdcI
X variable	AdcI
Y variable	Ik
Regression Statistics	
R Square	0.999993
Standard Error	2.8078e-008
Observations	1420

	Coefficients	*Standard Error*
Intercept (P0)	-3.4400e-008	1.283e-009
Slope (P1)	-1.8903e-009	1.332e-013

4.3.4.5 T_CEHS (alias FpuTemp03) plots



4.3.4.6 T_CEHS (alias FpuTemp03) linear transfer functions

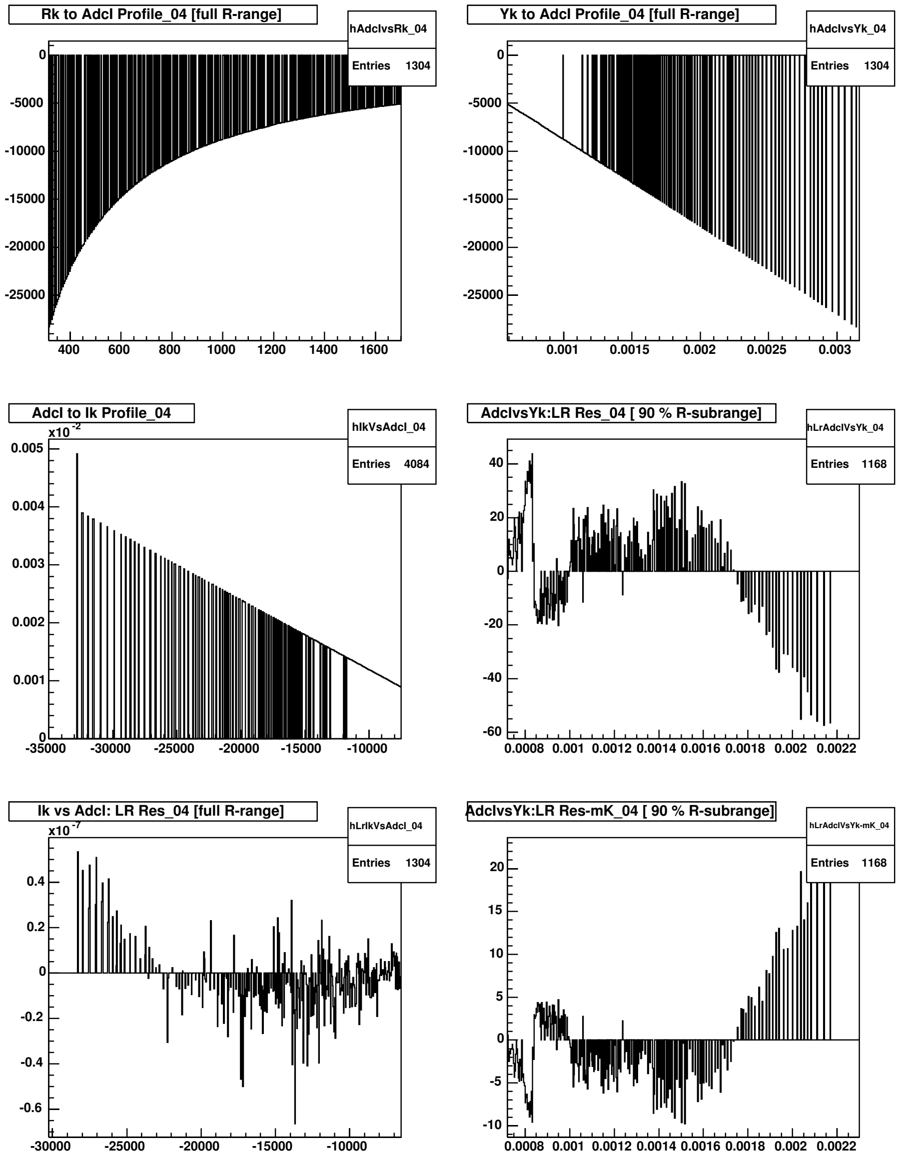
Channel	*T_CEHS [Alias FpuTemp03]*
R-SubRange	90%
Regression mode	LR_AdcIVsYk
X variable	Yk
Y variable	AdcI
Regression Statistics	
R Square	0.999959
Standard Error	2.0325e+001
Standard Error (mK equivalent)	1.0562e+001
Observations	1284

	Coefficients	*Standard Error*
Intercept (P0)	1.7659e+002	1.299e+000
Slope (P1)	-5.5231e+006	9.909e+002

Channel	*T_CEHS [Alias FpuTemp03]*
R-SubRange	90%
Regression mode	LR_IkVsAdcI
X variable	AdcI
Y variable	Ik
Regression Statistics	
R Square	0.999993
Standard Error	2.7588e-008
Observations	1420

	Coefficients	*Standard Error*
Intercept (P0)	-3.5449e-008	1.260e-009
Slope (P1)	-1.8902e-009	1.312e-013

4.3.4.7 T_CSHT (alias FpuTemp04) plots



4.3.4.8 T_CSHT (alias FpuTemp04) linear transfer functions

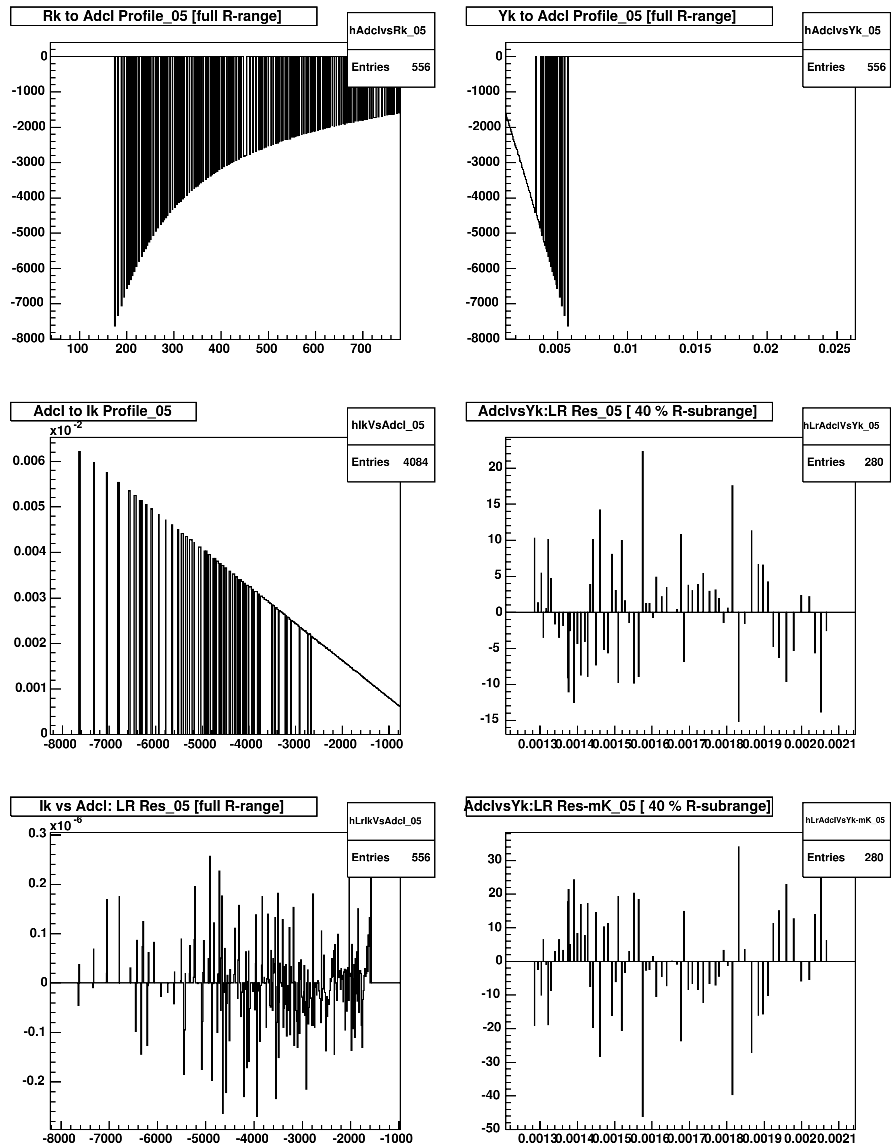
Channel	*T_CSHT [Alias FpuTemp04]*
R-SubRange	90%
Regression mode	LR_AdcIVsYk
X variable	Yk
Y variable	AdcI
Regression Statistics	
R Square	0.999961
Standard Error	2.2624e+001
Standard Error (mK equivalent)	6.0514e+000
Observations	1168

	Coefficients	*Standard Error*
Intercept (P0)	2.6222e+002	1.848e+000
Slope (P1)	-9.0251e+006	1.647e+003

Channel	*T_CSHT [Alias FpuTemp04]*
R-SubRange	90%
Regression mode	LR_IkVsAdcI
X variable	AdcI
Y variable	Ik
Regression Statistics	
R Square	0.999994
Standard Error	1.5958e-008
Observations	1304

	Coefficients	*Standard Error*
Intercept (P0)	-3.2419e-008	9.561e-010
Slope (P1)	-1.2002e-009	7.959e-014

4.3.4.9 T_SOB (alias FpuTemp05) plots



4.3.4.10 T_SOB (alias FpuTemp05) linear transfer functions

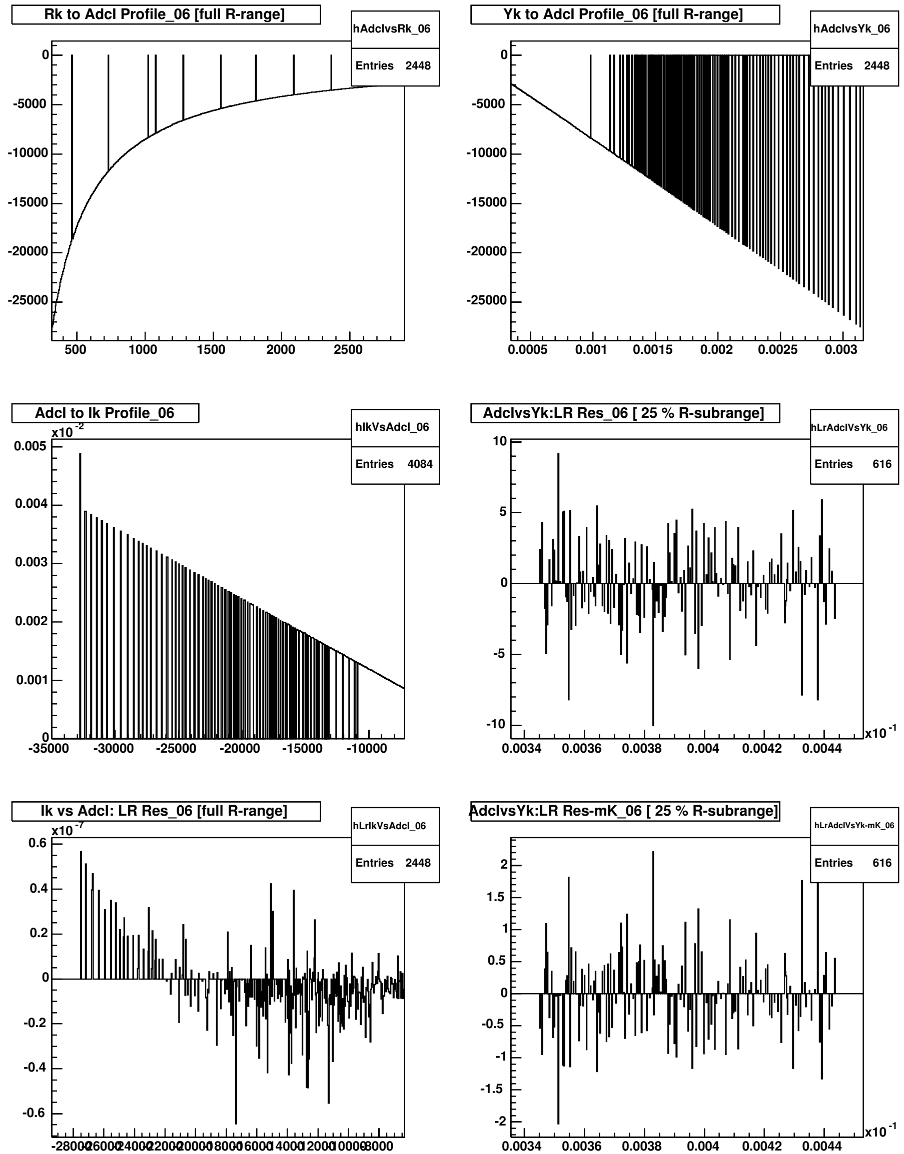
Channel	*T_SOB [Alias FpuTemp05]*
R-SubRange	40%
Regression mode	LR_AdcIVsYk
X variable	Yk
Y variable	AdcI
Regression Statistics	
R Square	0.997587
Standard Error	1.4494e+001
Standard Error (mK equivalent)	3.0572e+001
Observations	280

	Coefficients	*Standard Error*
Intercept (P0)	7.0031e+001	6.250e+000
Slope (P1)	-1.3024e+006	3.841e+003

Channel	*T_SOB [Alias FpuTemp05]*
R-SubRange	40%
Regression mode	LR_IkVsAdcI
X variable	AdcI
Y variable	Ik
Regression Statistics	
R Square	0.999916
Standard Error	1.0824e-007
Observations	556

	Coefficients	*Standard Error*
Intercept (P0)	-2.7272e-008	1.092e-008
Slope (P1)	-8.1471e-009	3.180e-012

4.3.4.11 T_SLO (alias FpuTemp06) plots



4.3.4.12 T_SLO (alias FpuTemp06) linear transfer functions

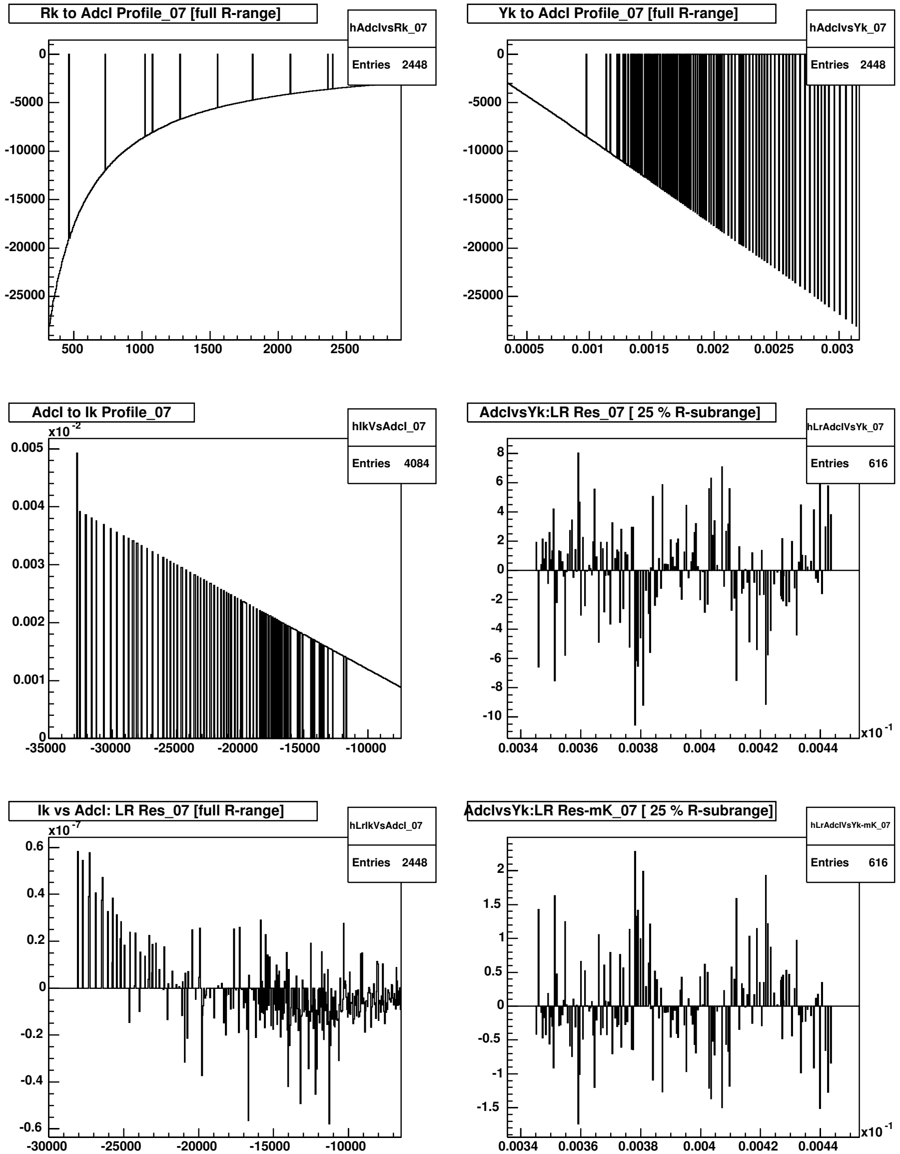
Channel	*T_SLO [Alias FpuTemp06]*
R-SubRange	25%
Regression mode	LR_AdcIVsYk
X variable	Yk
Y variable	AdcI
Regression Statistics	
R Square	0.999185
Standard Error	6.8916e+000
Standard Error (mK equivalent)	1.5227e+000
Observations	616

	Coefficients	*Standard Error*
Intercept (P0)	2.5456e+001	3.793e+000
Slope (P1)	-8.4170e+006	9.699e+003

Channel	*T_SLO [Alias FpuTemp06]*
R-SubRange	25%
Regression mode	LR_IkVsAdcI
X variable	AdcI
Y variable	Ik
Regression Statistics	
R Square	0.999995
Standard Error	1.3442e-008
Observations	2448

	Coefficients	*Standard Error*
Intercept (P0)	-2.0769e-008	4.688e-010
Slope (P1)	-1.1994e-009	5.266e-014

4.3.4.13 T_PLO (alias FpuTemp07) plots



4.3.4.14 T_PLO (alias FpuTemp07) linear transfer functions

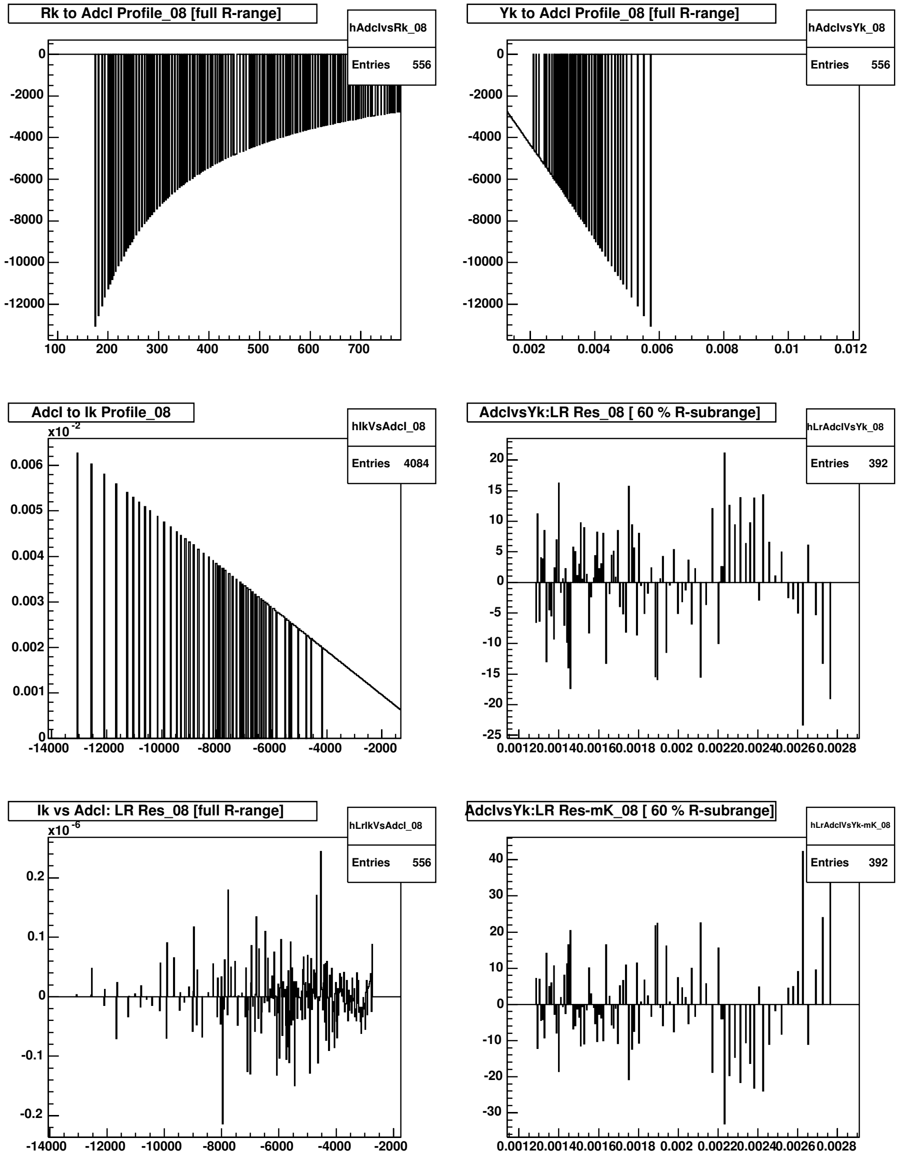
Channel	*T_PLO [Alias FpuTemp07]*
R-SubRange	25%
Regression mode	LR_AdcIVsYk
X variable	Yk
Y variable	AdcI
Regression Statistics	
R Square	0.999061
Standard Error	7.5613e+000
Standard Error (mK equivalent)	1.6347e+000
Observations	616

	Coefficients	*Standard Error*
Intercept (P0)	2.4134e+001	4.161e+000
Slope (P1)	-8.5985e+006	1.064e+004

Channel	*T_PLO [Alias FpuTemp07]*
R-SubRange	25%
Regression mode	LR_IkVsAdcI
X variable	AdcI
Y variable	Ik
Regression Statistics	
R Square	0.999995
Standard Error	1.4175e-008
Observations	2448

	Coefficients	*Standard Error*
Intercept (P0)	-2.2409e-008	4.947e-010
Slope (P1)	-1.1998e-009	5.444e-014

4.3.4.15 T_SUB (alias FpuTemp08) plots



4.3.4.16 T_SUB (alias FpuTemp08) linear transfer functions

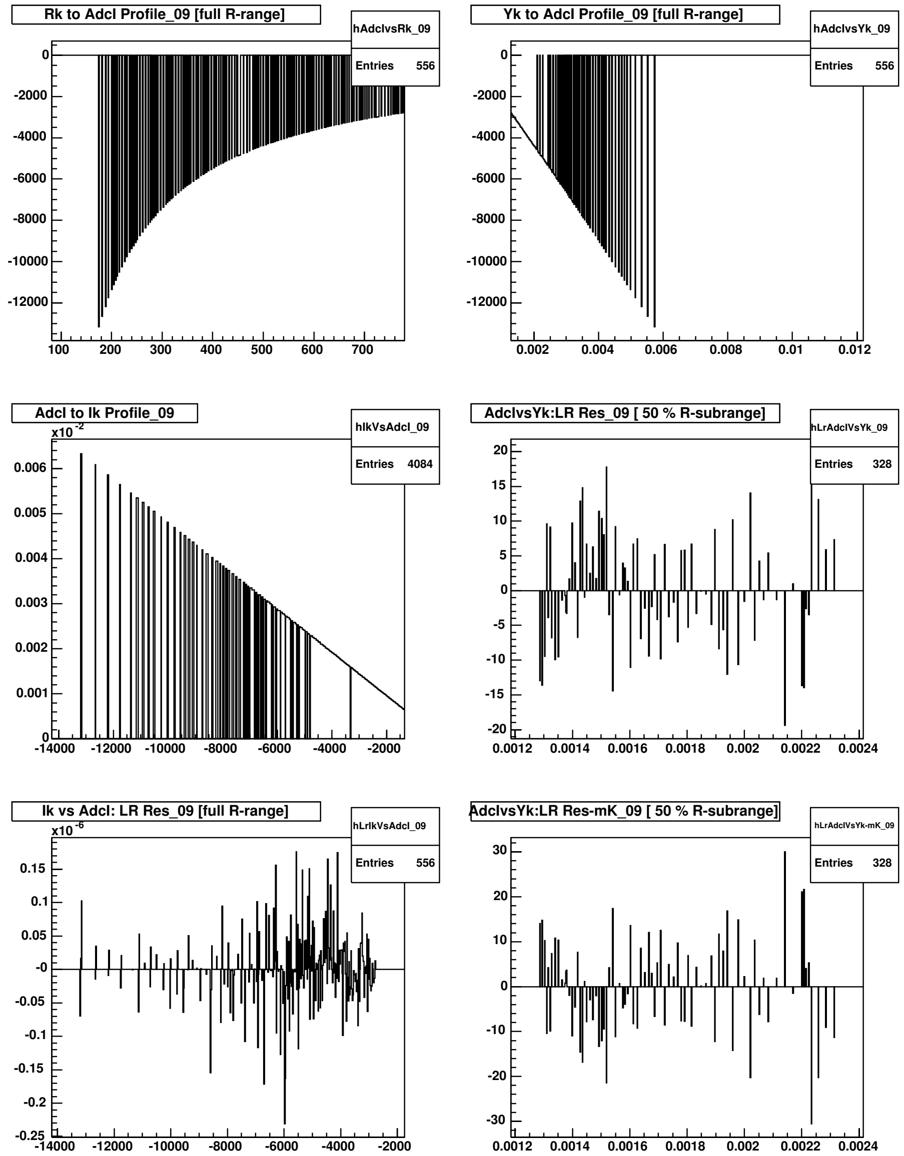
Channel	*T_SUB [Alias FpuTemp08]*
R-SubRange	60%
Regression mode	LR_AdcIVsYk
X variable	Yk
Y variable	AdcI
Regression Statistics	
R Square	0.999680
Standard Error	1.6477e+001
Standard Error (mK equivalent)	2.3047e+001
Observations	392

	Coefficients	*Standard Error*
Intercept (P0)	9.2730e+001	3.773e+000
Slope (P1)	-2.2125e+006	2.005e+003

Channel	*T_SUB [Alias FpuTemp08]*
R-SubRange	60%
Regression mode	LR_IkVsAdcI
X variable	AdcI
Y variable	Ik
Regression Statistics	
R Square	0.999966
Standard Error	6.9764e-008
Observations	556

	Coefficients	*Standard Error*
Intercept (P0)	-3.1133e-008	7.034e-009
Slope (P1)	-4.8056e-009	1.197e-012

4.3.4.17 T_BAF (alias FpuTemp09) plots



4.3.4.18 T_BAF (alias FpuTemp09) linear transfer functions

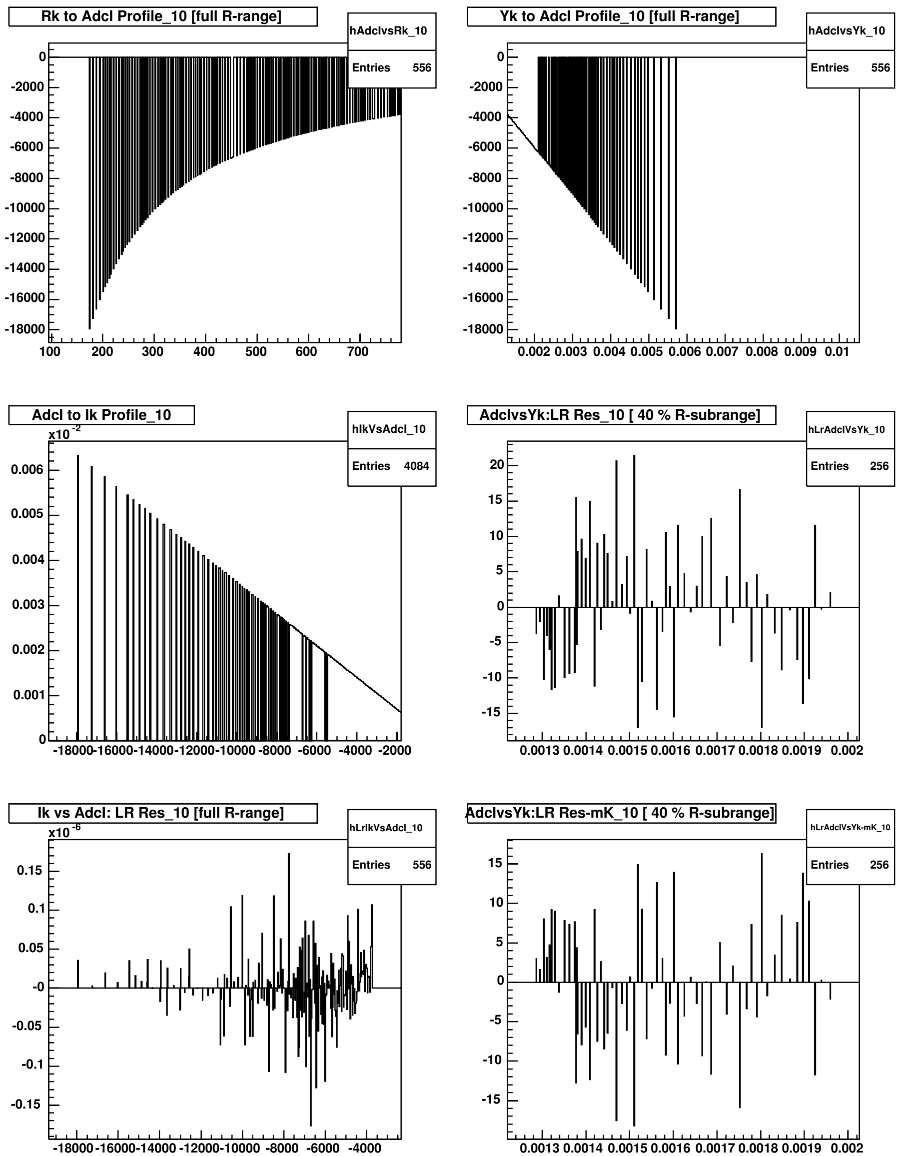
Channel	*T_BAF [Alias FpuTemp09]*
R-SubRange	50%
Regression mode	LR_AdcIVsYk
X variable	Yk
Y variable	AdcI
Regression Statistics	
R Square	0.999361
Standard Error	1.6769e+001
Standard Error (mK equivalent)	2.1898e+001
Observations	328

	Coefficients	*Standard Error*
Intercept (P0)	8.5596e+001	5.383e+000
Slope (P1)	-2.2306e+006	3.123e+003

Channel	*T_BAF [Alias FpuTemp09]*
R-SubRange	50%
Regression mode	LR_IkVsAdcI
X variable	AdcI
Y variable	Ik
Regression Statistics	
R Square	0.999964
Standard Error	7.1853e-008
Observations	556

	Coefficients	*Standard Error*
Intercept (P0)	-2.5739e-008	7.253e-009
Slope (P1)	-4.8121e-009	1.223e-012

4.3.4.19 T_BSMS (alias FpuTemp10) plots



4.3.4.20 T_BSMS (alias FpuTemp10) linear transfer functions

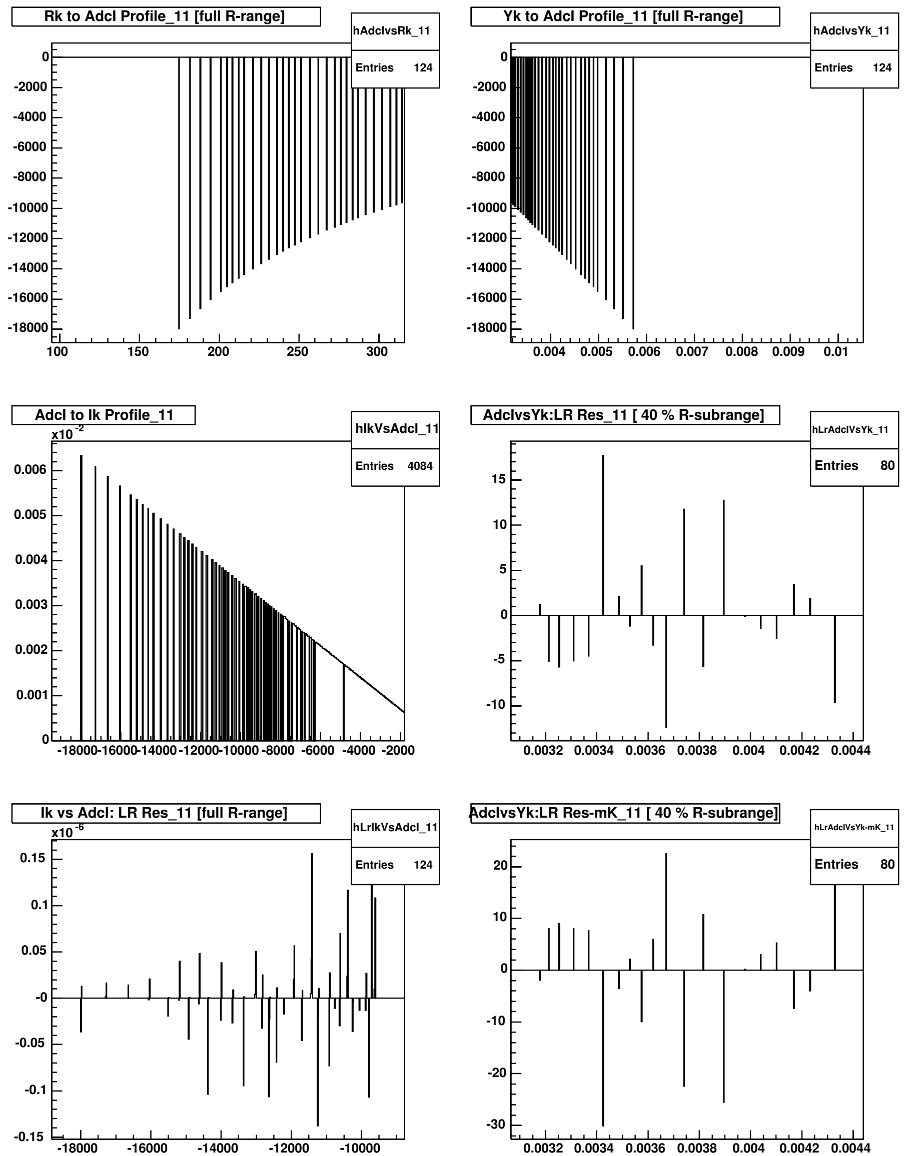
Channel	*T_BSMS [Alias FpuTemp10]*
R-SubRange	40%
Regression mode	LR_AdcIVsYk
X variable	Yk
Y variable	AdcI
Regression Statistics	
R Square	0.999137
Standard Error	1.7573e+001
Standard Error (mK equivalent)	1.5609e+001
Observations	256

	Coefficients	*Standard Error*
Intercept (P0)	1.5201e+002	8.940e+000
Slope (P1)	-3.0602e+006	5.643e+003

Channel	*T_BSMS [Alias FpuTemp10]*
R-SubRange	40%
Regression mode	LR_IkVsAdcI
X variable	AdcI
Y variable	Ik
Regression Statistics	
R Square	0.999980
Standard Error	5.3381e-008
Observations	556

	Coefficients	*Standard Error*
Intercept (P0)	-3.0444e-008	5.386e-009
Slope (P1)	-3.5232e-009	6.662e-013

4.3.4.21 T_SCL2 (alias FpuTemp11) plots



4.3.4.22 T_SCL2 (alias FpuTemp11) linear transfer functions

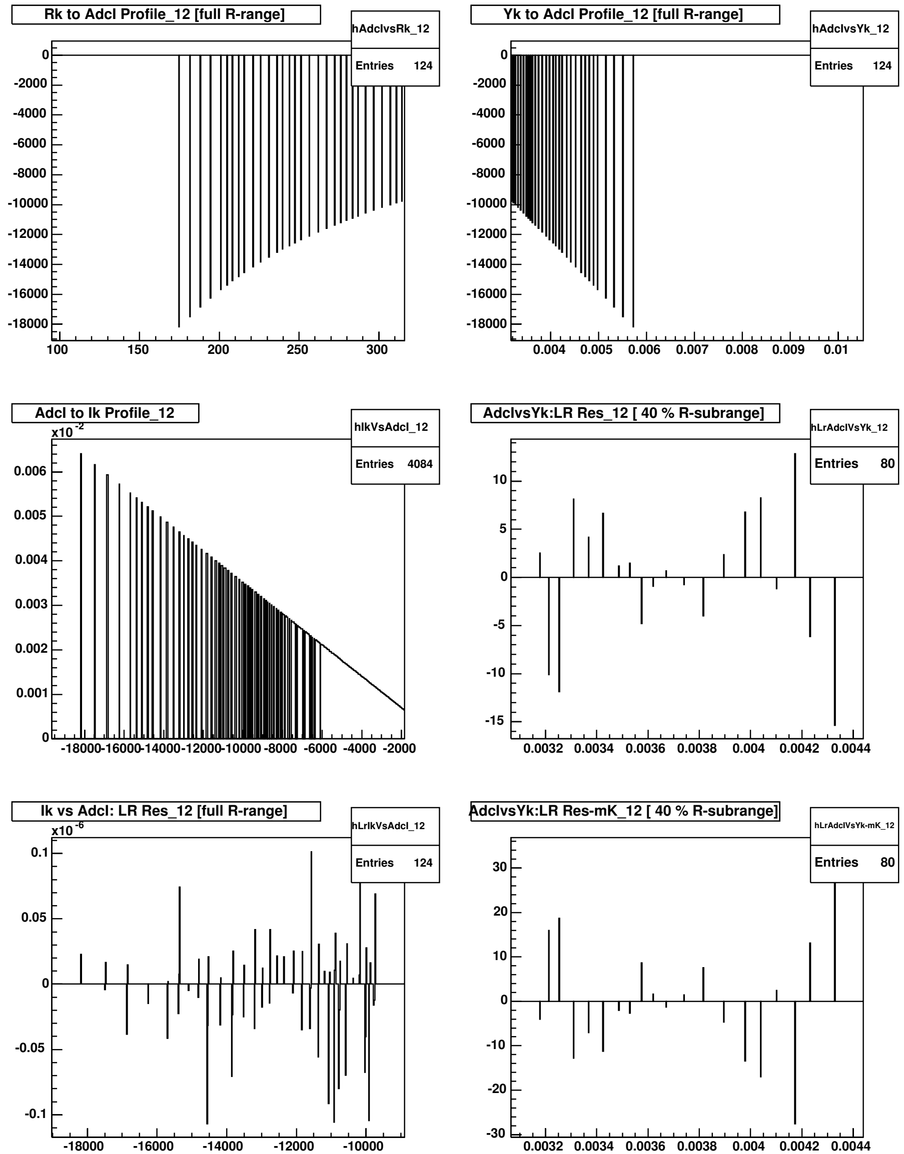
Channel	*T_SCL2 [Alias FpuTemp11]*
R-SubRange	40%
Regression mode	LR_AdcIVsYk
X variable	Yk
Y variable	AdcI
Regression Statistics	
R Square	0.999856
Standard Error	1.3709e+001
Standard Error (mK equivalent)	2.5097e+001
Observations	80

	Coefficients	*Standard Error*
Intercept (P0)	6.2177e+002	1.627e+001
Slope (P1)	-3.2251e+006	4.381e+003

Channel	*T_SCL2 [Alias FpuTemp11]*
R-SubRange	40%
Regression mode	LR_IkVsAdcI
X variable	AdcI
Y variable	Ik
Regression Statistics	
R Square	0.999974
Standard Error	4.1943e-008
Observations	124

	Coefficients	*Standard Error*
Intercept (P0)	-5.8714e-008	2.103e-008
Slope (P1)	-3.5267e-009	1.619e-012

4.3.4.23 T_SCL4 (alias FpuTemp12) plots



4.3.4.24 T_SCL4 (alias FpuTemp12) linear transfer functions

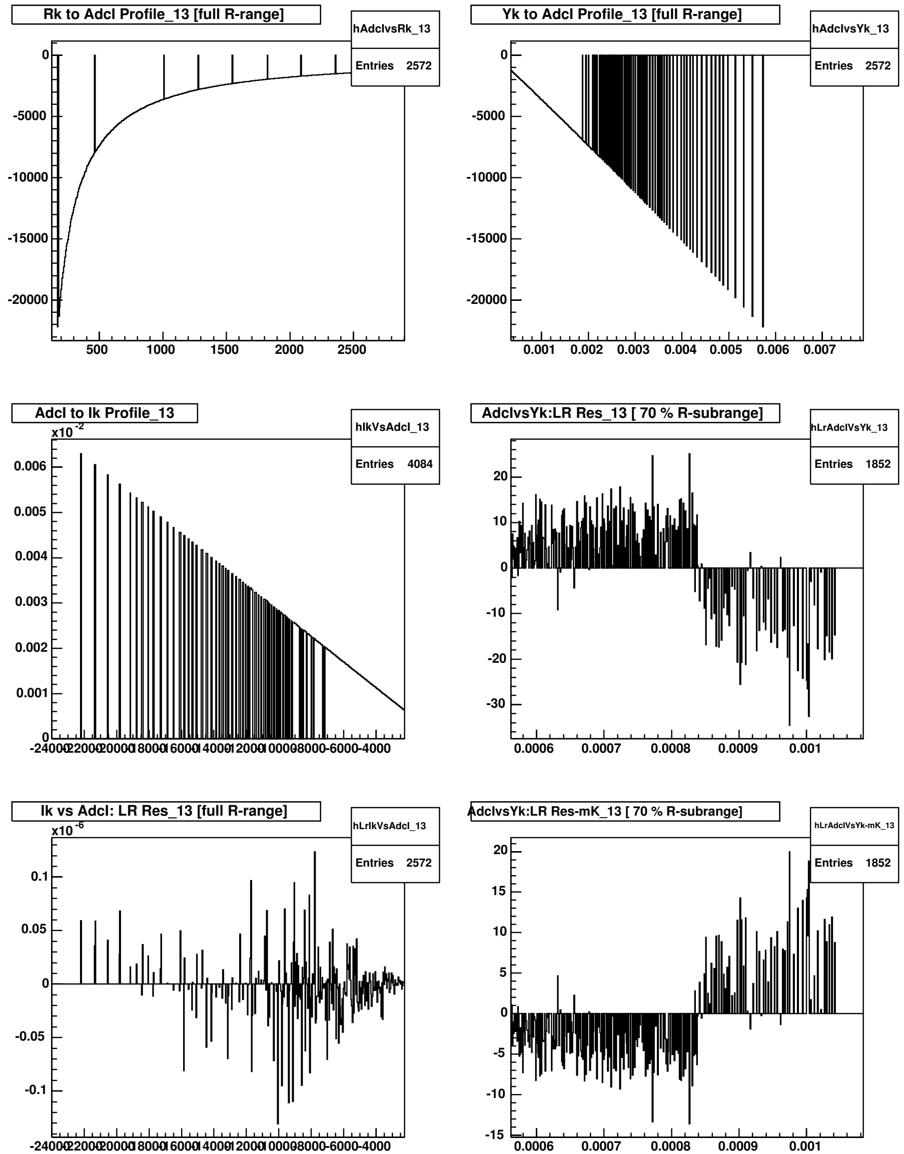
Channel	*T_SCL4 [Alias FpuTemp12]*
R-SubRange	40%
Regression mode	LR_AdcIVsYk
X variable	Yk
Y variable	AdcI
Regression Statistics	
R Square	0.999881
Standard Error	1.2603e+001
Standard Error (mK equivalent)	2.3102e+001
Observations	80

	Coefficients	*Standard Error*
Intercept (P0)	5.7966e+002	1.495e+001
Slope (P1)	-3.2524e+006	4.025e+003

Channel	*T_SCL4 [Alias FpuTemp12]*
R-SubRange	40%
Regression mode	LR_IkVsAdcI
X variable	AdcI
Y variable	Ik
Regression Statistics	
R Square	0.999980
Standard Error	3.7300e-008
Observations	124

	Coefficients	*Standard Error*
Intercept (P0)	-8.7422e-008	1.873e-008
Slope (P1)	-3.5281e-009	1.424e-012

4.3.4.25 T_SCST (alias FpuTemp13) plots



4.3.4.26 T_SCST (alias FpuTemp13) linear transfer functions

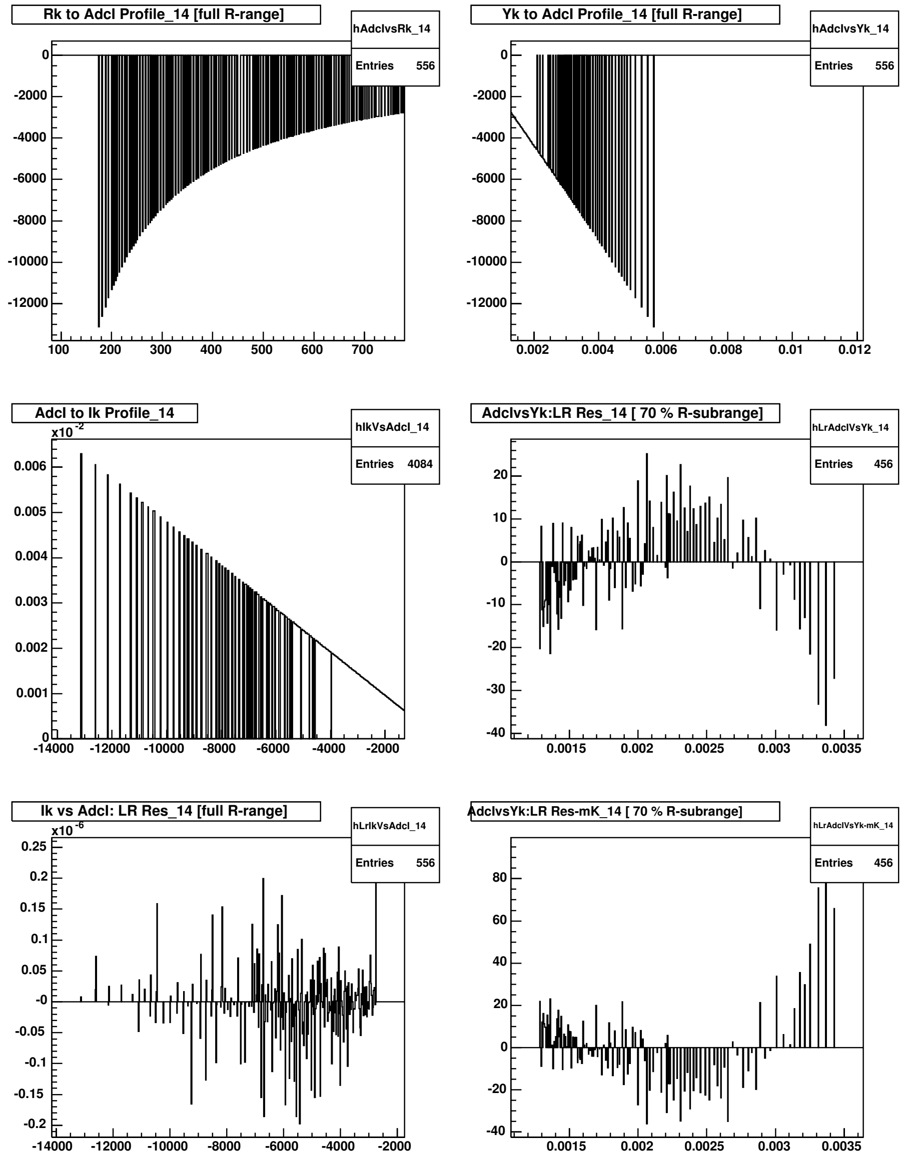
Channel	*T_SCST [Alias FpuTemp13]*
R-SubRange	70%
Regression mode	LR_AdcIVsYk
X variable	Yk
Y variable	AdcI
Regression Statistics	
R Square	0.999695
Standard Error	1.1919e+001
Standard Error (mK equivalent)	6.3960e+000
Observations	1852

	Coefficients	*Standard Error*
Intercept (P0)	3.4396e+001	8.903e-001
Slope (P1)	-3.6434e+006	1.481e+003

Channel	*T_SCST [Alias FpuTemp13]*
R-SubRange	70%
Regression mode	LR_IkVsAdcI
X variable	AdcI
Y variable	Ik
Regression Statistics	
R Square	0.999990
Standard Error	3.2326e-008
Observations	2572

	Coefficients	*Standard Error*
Intercept (P0)	-1.9960e-008	9.253e-010
Slope (P1)	-2.8366e-009	1.811e-013

4.3.4.27 T_FTSS (alias FpuTemp14) plots



4.3.4.28 T_FTSS (alias FpuTemp14) linear transfer functions

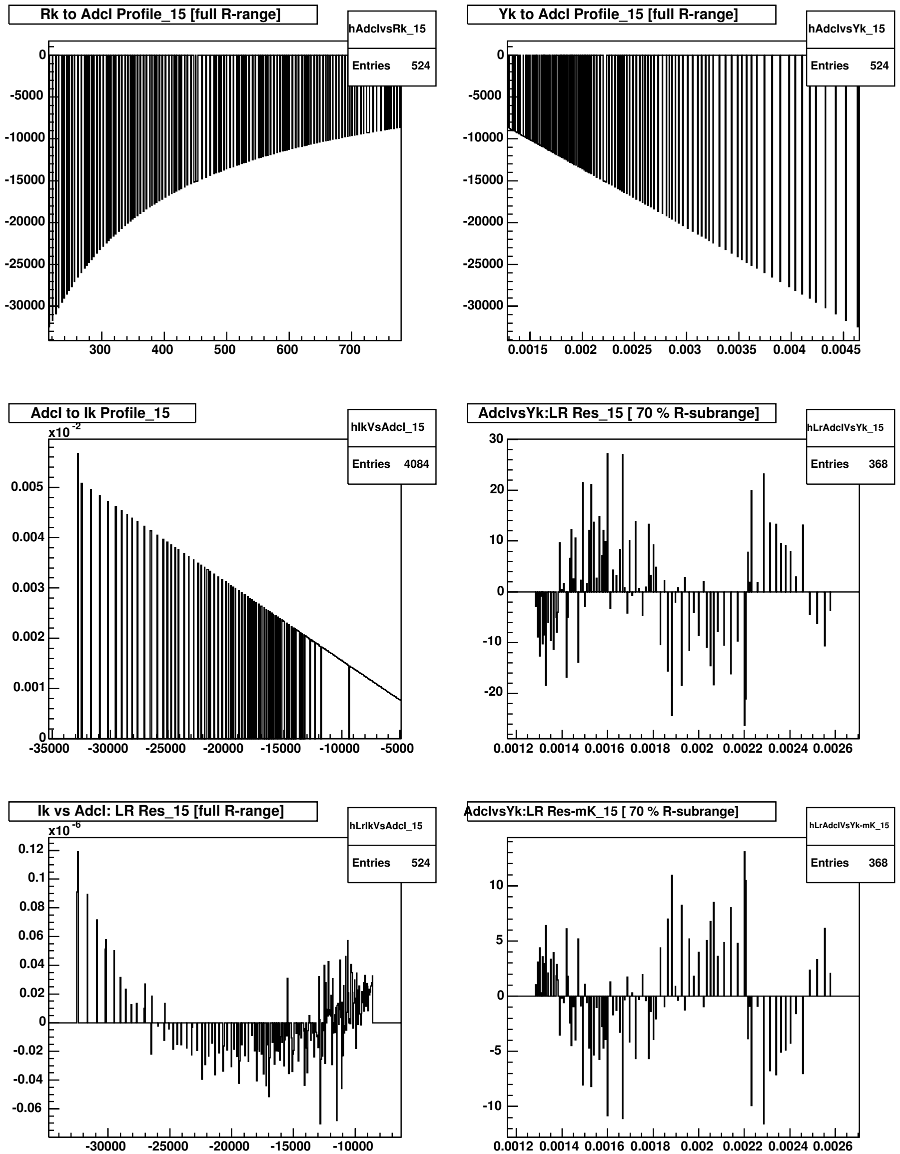
Channel	*T_FTSS [Alias FpuTemp14]*
R-SubRange	70%
Regression mode	LR_AdcIVsYk
X variable	Yk
Y variable	AdcI
Regression Statistics	
R Square	0.999820
Standard Error	1.7691e+001
Standard Error (mK equivalent)	2.8162e+001
Observations	456

	Coefficients	*Standard Error*
Intercept (P0)	1.3530e+002	2.968e+000
Slope (P1)	-2.2512e+006	1.418e+003

Channel	*T_FTSS [Alias FpuTemp14]*
R-SubRange	70%
Regression mode	LR_IkVsAdcI
X variable	AdcI
Y variable	Ik
Regression Statistics	
R Square	0.999965
Standard Error	7.0432e-008
Observations	556

	Coefficients	*Standard Error*
Intercept (P0)	-1.6681e-008	7.103e-009
Slope (P1)	-4.8035e-009	1.201e-012

4.3.4.29 T_FTSM (alias FpuTemp15) plots



4.3.4.30 T_FTSM (alias FpuTemp15) linear transfer functions

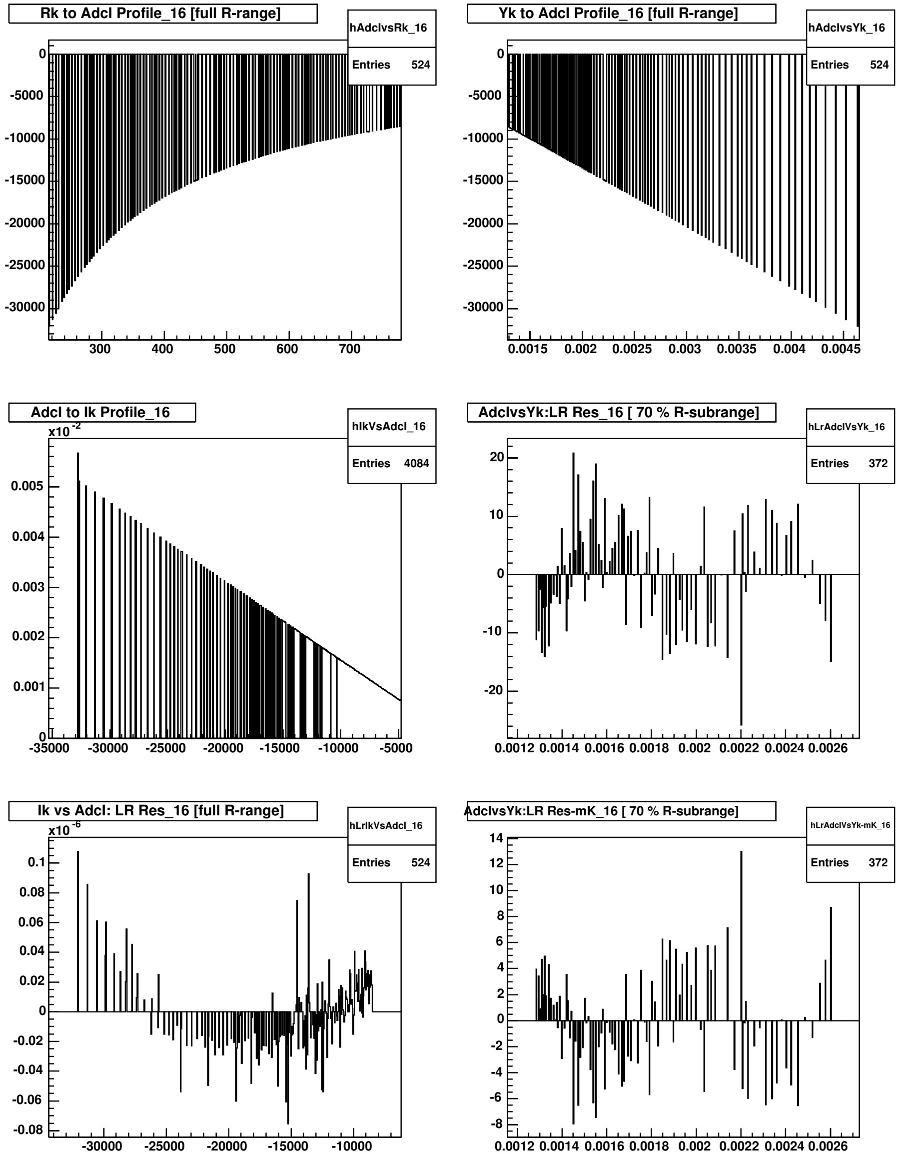
Channel	*T_FTSM [Alias FpuTemp15]*
R-SubRange	70%
Regression mode	LR_AdcIVsYk
X variable	Yk
Y variable	AdcI
Regression Statistics	
R Square	0.999952
Standard Error	1.7672e+001
Standard Error (mK equivalent)	7.5273e+000
Observations	368

	Coefficients	*Standard Error*
Intercept (P0)	3.0666e+002	4.576e+000
Slope (P1)	-6.9371e+006	2.518e+003

Channel	*T_FTSM [Alias FpuTemp15]*
R-SubRange	70%
Regression mode	LR_IkVsAdcI
X variable	AdcI
Y variable	Ik
Regression Statistics	
R Square	0.999989
Standard Error	3.1499e-008
Observations	524

	Coefficients	*Standard Error*
Intercept (P0)	-9.6158e-008	3.732e-009
Slope (P1)	-1.5649e-009	2.241e-013

4.3.4.31 T_BSMM (alias FpuTemp16) plots



4.3.4.32 T_BSMM (alias FpuTemp16) linear transfer functions

Channel	*T_BSMM [Alias FpuTemp16]*
R-SubRange	70%
Regression mode	LR_AdcIVsYk
X variable	Yk
Y variable	AdcI
Regression Statistics	
R Square	0.999961
Standard Error	1.6021e+001
Standard Error (mK equivalent)	6.9234e+000
Observations	372

	Coefficients	*Standard Error*
Intercept (P0)	3.0775e+002	4.062e+000
Slope (P1)	-6.8559e+006	2.223e+003

Channel	*T_BSMM [Alias FpuTemp16]*
R-SubRange	70%
Regression mode	LR_IkVsAdcI
X variable	AdcI
Y variable	Ik
Regression Statistics	
R Square	0.999990
Standard Error	2.9644e-008
Observations	524

	Coefficients	*Standard Error*
Intercept (P0)	-8.7781e-008	3.511e-009
Slope (P1)	-1.5637e-009	2.134e-013

4.3.5 Tabulated full range response

The linear analysis shows that most channels cannot be simply described by a linear response with the current range and/or accuracy requirements. The effect of power and board temperature variations is not yet assessed. We may expect slightly different responses from distinct CERNOX probes. Due to that, we may expect that the compound [(Temperature to Resistance) >> (Resistance to ADC value)] will eventually be tabulated for each channel. In anticipation, the actual response function for the full test resistor load range is given for reference in a separate spreadsheet file (measurement at laboratory temperature, ~25℃).

5 SubKTemp tests

This section gives the test conditions and results for the SubKTemp analogue channel.

5.1 SubKTemp test configuration

Due to the very low AC bias current level (I_L = ±40 nA), the SubKTemp (alias T_CEV) channel cannot be easily instrumented for testing. The channel 4-wire interface is connected to a variable load resistor R_L, implemented by a digital potentiometer (Analog Devices AD8403). Alternately, a calibrated DC-resistance box is used (AOIP ZX76) to load the channel and inter-calibrate the digital potentiometer resistance.

5.2 SubKTemp channel characteristics

Table 30 recalls the the SubKTemp channel name, alias and temperature range specifications. Using a typical CERNOX probe calibration table, the corresponding load resistance range [Rmin..Rmax] was derived. The resolution (Res) and accuracy (Acc) requirements are also indicated.

Name	Alias	Tmin (K)	Tmax (K)	Rmin (Ω)	Rmax (Ω)	Res (mK)	Acc (mK)
T_CEV	SubKTemp	0.25	10.	316	150000	0.1	5.

Table 32 SubKTemp channel characteristics

The SubKTemp circuit biases the resistor load with a fixed 10 Hz ±40 nA alternative current. The differential AC bias method is used to suppress the low frequency noise contribution. The voltage across the load resistor is sampled and held on both the positive and negative phases of the current production. The Vp and Vn samples are substracted to obtain the (Vp-Vn) ~ 2 V_L differential measurement of the load voltage. This voltage is then amplified to fit to the ADC range. The resulting ADCv measurement is thus proportional to the load resistance R_L.

5.3 SubKTemp channel tests

5.3.1 Method

The channel response is a measurement of the resistor load voltage V_L but the V_L value cannot be independently measured in the current setup. The channel resistor range is explored by varying R_L. The R_L-to-AdcV response is then globally analysed to assess the compound effect of errors in the source current production and errors in the voltage measurement.

The linearity of the R_L to ADCv transfer function is assessed by linear regression (analysis of variance method). For each measurement point, the residual error from the fit (expressed in ADC step units) is then translated to temperature equivalents (expressed in mK), taking the derivative of the (typical) CERNOX Y-to-T transfer curve at this particular point.

5.3.2 Analysis

Although the conceptual R_L to ADCv transfer function is linear, the actual SubKTemp channel show small integral and differential non linearity effects. In the high temperature (low CERNOX resistance)

side of the range, small errors in the measurement of R_L translate into very large errors in temperature, due to the very small T-to-R sensibility of the CERNOX probe in this region. The response cannot be given as a simple 2-parameter linear function because the systematic error on the high temperature side of the channel range exceeds the accuracy requirement.

5.3.3 Linear sub-range

It is understood that the important usage area of the SubKTemp channel is the low temperature (high CERNOX resistance) side of the range. We felt useful to understand the low-temperature fraction of the usage range where the channel response can be expressed as a linear function and still fulfill the accuracy requirement.

For this analysis, we restricted the resistance range towards the low temperature side until we found the required accuracy. The resulting acceptance sub-range is given in Table 33 .

Name	Alias	R-SubRange (%)	Rmin (Ω)	Rmin SubRange (Ω)	Rmax (Ω)	Tmin (K)	Tmax SubRange (K)	Tmax (K)	Acc (mK)
T_CEV	SubKTemp	98.	316	3309	1700	0.25	0.95	10.	5.

Table 33 FPUTemp channel linear sub-ranges

The temperature sub-range linear acceptance fraction is less than 10%.

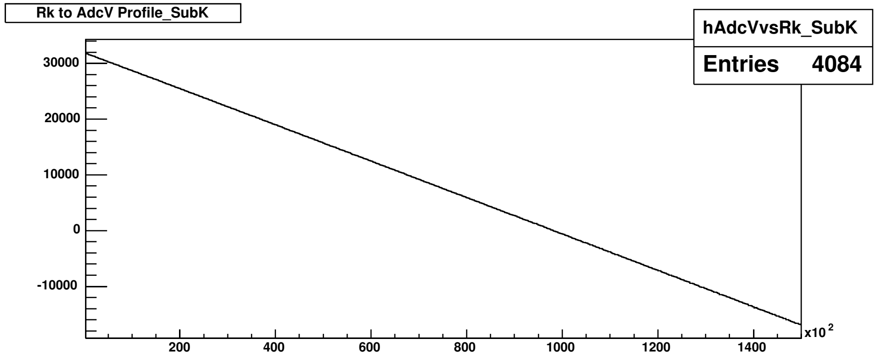
5.3.4 SubKTemp response

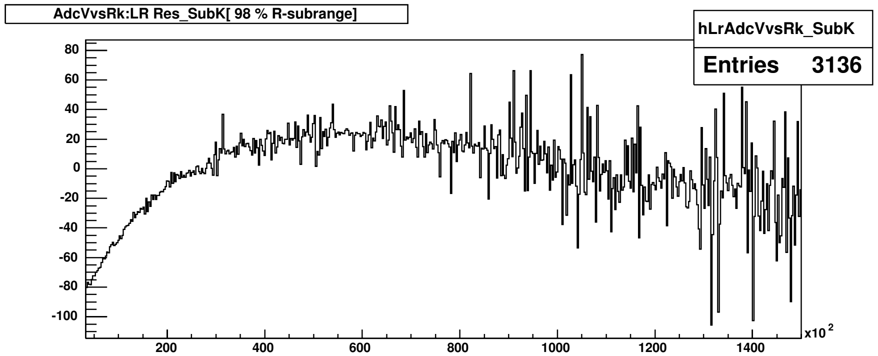
The corresponding full range dependency and sub-range linear fit residue plots are given in the following. The residue plots expressed in mK equivalents are given for reference.

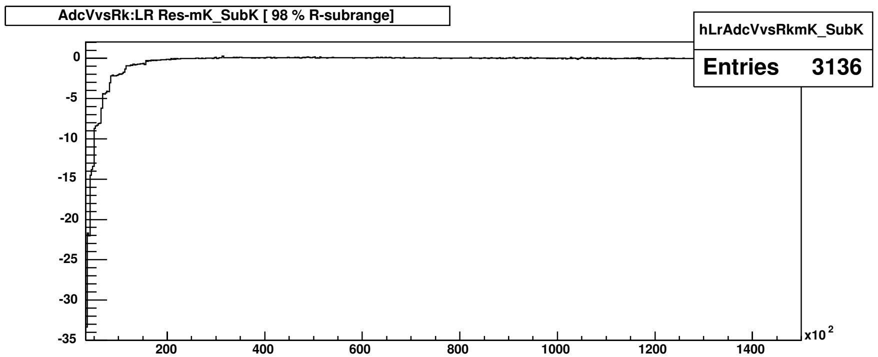
The following plots give:

- The ADCv = f(Rk) dependency histogram (hAdcVvsRk_SubK), obtained when sweeping the load resistance inside the channel [Rmin..Rmax] range (full R-Range);
- The corresponding linear fit residual plots [AdcVvsYk: LR Res_SubK (ADC step units), AdcVvsYk: LR Res-mK_SubK (mK-equivalent units)], restricted to the channel accuracy subrange;

5.3.4.1 T_CEV (alias SubKTemp) plots







5.3.4.2 T_CEV (alias SubKTemp) transfer function

Channel	*T_CEV [Alias SubKTemp]*
R-SubRange	98%
Regression mode	LR_AdcVvsRk
X variable	Rk
Y variable	AdcV
Regression Statistics	
R Square	0.999996
Standard Error	2.9017e+001
Standard Error (mK equivalent)	2.3465e+000
Observations	3136

	Coefficients	*Standard Error*
Intercept (P0)	3.2008e+004	1.074e+000
Slope (P1)	-3.2606e-001	1.225e-005

6 Miscellaneous tests

This section gives the test conditions and results for the miscellaneous analogue channels.

6.1 Electronics Temp. Monitor : TempMon

As specified in AD 1, the electronics temperature monitoring channels use the AD590 sensor. The sensor current is converted to voltage with a 1kΩ resistance. The 1µA/K current dependence is thus translated to 1mV/K on the resistance voltage and to 6.55 ADC steps/K in the voltage to ADC conversion.

The circuit transfer function is: $T(K) = ADC_{code} * 1E+03 * (10 / 65536)$.

Figure 22 gives the evolution of the sensors during a night run dedicated to PhCal stability. The absolute calibration can be retrieved from the temperature tests performed during DRCU integration.

6.2 Power Supply Monitor : PwrMon

6.2.1 Transfer functions

The power supply monitoring channels use simple voltage dividers, and are readout through the common ADC system (Figure 2). The +9VDC, -9VDC and +5V PSU supplies are monitored. In addition, the internal +2.5VDC supply (used by the FPGA) and various DC reference voltages are also monitored.

The circuit transfer functions are given in Table 34 .

Housekeeping voltage	Voltage to ADC transfer function	With Nominal voltage	With Nominal voltage +20%
V_{hsk_P9}	$V_{SCU\_ANA\_P9}$ * 0.450 * (65536 / 10)	26660 (±500steps) ($6824)	31992 (±500steps) ($7CF8)
V_{hsk_N9}	$V_{SCU\_ANA\_N9}$ * 0.450 * (65536 / 10)	-26660 (±500steps) ($97DB)	-31992 (±500steps) ($8307)
V_{hsk_P5}	$V_{SCU\_ANA\_P5}$ * 0.785 * (65536 / 10)	26214 (±300steps) ($6666)	31457 (±300steps) ($7AE1)
$V_{hsk\_CCHKref}$	V_{ref02_CCHK} * 0.496 * (65536 / 10)	16252 ($3F7C)	/
$V_{hsk\_CCHKgnd}$	V_{gnd_CCHK} * 1.000 * (65536 / 10)	0 ($0000)	/
$V_{hsk\_CCHKp25}$	V_{DIG_2V5} * 1.000 * (65536 / 10)	16384 ($4000)	/
$V_{hsk\_TEMPref}$	V_{ref02_TEMP} * 0.496 * (65536 / 10)	16252 ($3F7C)	/
$V_{hsk\_TEMPgnd}$	V_{gnd_TEMP} * 1.000 * (65536 / 10)	0 ($0000)	/

Table 34 Circuit transfer functions

6.2.2 Typical test session log

The following test log extract give the values obtained under nominal conditions. The voltage equivalents are calculated according to the transfer functions defined in §6.2.1.


```
ScuCHTp05= 6472( 25714)[  5.00 V]  ScuCHTp09= 6776( 26486)[  8.98 V]
ScuCHTn09= 9868(-26520)[ -8.99 V]  ScuCHTp25= 405c( 16476)[  2.51 V]
ScuCHTref= 3f17( 16151)[  4.97 V]  ScuCHTgnd= 0000(     0)[  0.00 V]
ScuTHTref= 3f15( 16149)[  4.97 V]  ScuTHTgnd= fffd(    -3)[ -0.00 V]

ScuCHTp05= 6475( 25717)[  5.00 V]  ScuCHTp09= 6776( 26486)[  8.98 V]
ScuCHTn09= 9865(-26523)[ -8.99 V]  ScuCHTp25= 405a( 16474)[  2.51 V]
ScuCHTref= 3f16( 16150)[  4.97 V]  ScuCHTgnd= fffe(    -2)[ -0.00 V]
ScuTHTref= 3f16( 16150)[  4.97 V]  ScuTHTgnd= ffff(    -1)[ -0.00 V]

ScuCHTp05= 6474( 25716)[  5.00 V]  ScuCHTp09= 6776( 26486)[  8.98 V]
ScuCHTn09= 9867(-26521)[ -8.99 V]  ScuCHTp25= 405a( 16474)[  2.51 V]
ScuCHTref= 3f15( 16149)[  4.97 V]  ScuCHTgnd= fffe(    -2)[ -0.00 V]
ScuTHTref= 3f15( 16149)[  4.97 V]  ScuTHTgnd= fffe(    -2)[ -0.00 V]

ScuCHTp05= 6476( 25718)[  5.00 V]  ScuCHTp09= 6777( 26487)[  8.98 V]
ScuCHTn09= 9867(-26521)[ -8.99 V]  ScuCHTp25= 405b( 16475)[  2.51 V]
ScuCHTref= 3f16( 16150)[  4.97 V]  ScuCHTgnd= ffff(    -1)[ -0.00 V]
ScuTHTref= 3f17( 16151)[  4.97 V]  ScuTHTgnd= fffe(    -2)[ -0.00 V]

ScuCHTp05= 6475( 25717)[  5.00 V]  ScuCHTp09= 6777( 26487)[  8.98 V]
ScuCHTn09= 9866(-26522)[ -8.99 V]  ScuCHTp25= 405d( 16477)[  2.51 V]
ScuCHTref= 3f15( 16149)[  4.97 V]  ScuCHTgnd= fffe(    -2)[ -0.00 V]
ScuTHTref= 3f16( 16150)[  4.97 V]  ScuTHTgnd= 0000(     0)[  0.00 V]

ScuCHTp05= 6476( 25718)[  5.00 V]  ScuCHTp09= 6778( 26488)[  8.98 V]
ScuCHTn09= 9866(-26522)[ -8.99 V]  ScuCHTp25= 405c( 16476)[  2.51 V]
ScuCHTref= 3f16( 16150)[  4.97 V]  ScuCHTgnd= ffff(    -1)[ -0.00 V]
ScuTHTref= 3f17( 16151)[  4.97 V]  ScuTHTgnd= fffe(    -2)[ -0.00 V]

ScuCHTp05= 6476( 25718)[  5.00 V]  ScuCHTp09= 6777( 26487)[  8.98 V]
ScuCHTn09= 9866(-26522)[ -8.99 V]  ScuCHTp25= 405a( 16474)[  2.51 V]
ScuCHTref= 3f14( 16148)[  4.97 V]  ScuCHTgnd= 0000(     0)[  0.00 V]
ScuTHTref= 3f16( 16150)[  4.97 V]  ScuTHTgnd= 0000(     0)[  0.00 V]

ScuCHTp05= 6475( 25717)[  5.00 V]  ScuCHTp09= 6778( 26488)[  8.98 V]
ScuCHTn09= 9864(-26524)[ -8.99 V]  ScuCHTp25= 405d( 16477)[  2.51 V]
ScuCHTref= 3f15( 16149)[  4.97 V]  ScuCHTgnd= ffff(    -1)[ -0.00 V]
ScuTHTref= 3f17( 16151)[  4.97 V]  ScuTHTgnd= ffff(    -1)[ -0.00 V]
```

7 Transfer functions (summary)

This section gives a summary of the analogue channel transfer functions and compares the calculated expressions with the measurements performed on the QM1 model.

7.1 Calib/Heater transfer functions

The following summary table gives the analytic transfer function for the various analogue channel settings and measurements, and the corresponding DAC and ADC variation range. The theoretical values for the transfer function parameters are computed from the installed gain and offset of each analogue chain. The actual transfer functions obtained by statistical analysis of the QM1 measurements (see §3 for details) are slightly different, due to the electronic component spread and possible temperature effects. They are recalled in the table for comparison.

The Heater and Calibrator current sources and current/voltage monitoring circuits are linear. The slope (`p1` parameter), intercept (`p0` parameter) and variation range of the corresponding `y=p1*x+p0` functions are discussed in the following.

7.1.1 Assumptions

The following discussion and table assume the following (all other parameters nominal) :

- R=200 Ω for the Photometer calibrator resistance;
- R=40 Ω worst case harness resistance for the Sorption Pump Heater.

7.1.2 Calibrator current source offsets

The PhCal and SCal2/SCal4 current sources (set by parameters **PhCalCurSP**, **Scal2CurSP** and **Scal4CurSP**) include a negative offset circuit (`p0` parameter). This circuit guarantees that the applied current is forced to zero (degenerating to a diode leakage current) when the DAC code is below a low threshold value, and only starts to increase when the DAC code is above this threshold. The nominal threshold, calculated from ideal component values, is set to DAC code = 5. The actual threshold may end up at a slightly different value in the real circuit, and is determined by measurement.

7.1.3 Calib/Heater current and voltage monitoring offsets

The Calibrator and Heater current and voltage monitoring circuits (read by parameters **PhCalCur**, **Scal2Cur**, **Scal4Cur**, **PhCalVolt**, **Scal2Volt**, **Scal4Volt**, **Scal4Volt**, **EVHSHeatVolt**, **SPHSHeatVolt, SPHeaterVolt**, **EVHSHeat** and **TCHeaterVolt**) do not add offset, and the corresponding theoretical `p0` parameter value is always zero. The actual (small, positive or negative) `p0` parameter value, resulting from residual component offsets, is obtained by measurement. Due to the bipolar voltage range of the ADCs, the pedestal noise characteristics in the absence of signal may still be studied even if resulting in a negative value.

7.1.4 SPHeater saturation

The SPHeater current source behaves linearly until the load voltage reaches ~15.6 V, where it enters saturation. However, there is sufficient margin to insure that the current required to obtain a 0.5 W dissipation on the 402 Ω load [sqrt(0.5/402)=35.2 mA] is reachable even under the worst case operating conditions (40 Ω harness resistance, low ±9V DC power supplies).

7.1.5 Calibrator transfer functions

Parameter Name	Usage	Transfer function	Theoretical values[1]	QM1 25°C measurements [value (standard error)]	Variation range[2]
PhCalCurSP	*Set current applied to Photometer Calibrator*	I_L=p1*DAC+p0	p1=1.75E-6A p0=-7.16E-6A	p1=1.749725E-06 (6.2E-13) p0=-7.201E-06 (1.5E-09)	[0..4]⇒ [0.00E-3A] [5..4095]⇒ [0.00E-3A..7.16E-3A]
PhCalCur	*Measure current applied to Photometer Calibrator*	ADCi=round (p1*I_L+p0)	p1=4.03E+6 p0=0.	p1=402798.E+01 (10.) p0=-1.17 (0.042)	[0.00E-3A..7.16E-3A]⇒ [0..28831]
PhCalVolt	*Measure voltage of Photometer Calibrator*	ADCv=p1*V_L+p0	p1=1.96E+4 p0=0.	p1=19659.35 (0.040) p0=-0.67 (0.034)	[0.00E-3V..1.43E+0V]⇒ [0..28143]
SCal2CurSP	*Set current applied to Spectrometer Calibrator 2%*	I_L=p1*DAC+p0	p1=1.36E-6A p0=-5.58E-6A	p1=1.363062E-06 (5.7E-13) p0=-5.476E-06 (1.3E-09)	[0..4]⇒ [0.00E-6A] [5..4095]⇒ [0.00E-3A..5.58E-3A]
Scal4CurSP	*Set current applied to Spectrometer Calibrator 4%*			p1=1.362775E-06 (5.3E-13) p0=-5.667E-06 (1.3E-09)	[0..4]⇒ [0.00E-6A] [5..4095]⇒ [0.00E-3A..5.58E-3A]
SCal2Cur	*Measure current applied to Spectrometer Calibrator 2%*	ADCi=p1*I_L+p0	p1=5.63E+6 p0=0.	p1=563018.E+01 (16.) p0=0.81 (0.052)	[0.00E-3A..5.58E-3A]⇒ [0..31396]
Scal4Cur	*Measure current applied to Spectrometer Calibrator 4%*			p1=562795.E+01 (15.) p0=0.19 (0.048)	[0.00E-3A..5.58E-3A]⇒ [0..31383]
Scal2Volt	*Measure voltage of Spectrometer Calibrator 2%*	ADCv=p1*V_L+p0	p1=1.00E+4 p0=0.	p1=10015.42 (0.021) p0=-1.62 (0.034)	[0.00E-3V..2.79E+0V]⇒ [0..27923]
Scal4Volt	*Measure voltage of Spectrometer Calibrator 4%*			p1=10005.7 (0.021) p0=-1.25 (0.034)	[0.00E-3V..2.79E+0V]⇒ [0..27896]

Table 35 Calibrator transfer functions

[1] The theoretical slope and intercept values are ideal computations derived from the installed nominal circuit component values (0.1% resistors are used in the QM1). They are given to 0.1% relative precision. They do not take component spread and temperature variation into account. The unit used for the `p0` parameter of zero offset circuits is arbitrary.

[2] The expressed ADC values result from raw calculation of the range boundaries. They do not imply precision to the last digit.

7.1.6 Heater transfer functions

Parameter Name	Usage	Transfer function	Theoretical values[3]	QM1 25℃ measurements [value (standard error)]	Variation range[4]
EVHSHeatCur	*Set current of Evaporator Heat Switch heater*	I_L=p1*DAC+p0	p1=3.94E-7A p0=0.	p1=3.9357E-07 (8.2E-12) p0=-2.44E-06 (1.9E-08)	[0..4095]⇒ [0.00E-3A..1.61E-3A]
SPHSHeatCur	*Set current of Sorption Pump Heat Switch heater*			p1=3.9353E-07 (6.1E-12) p0=-2.05E-06 (1.45E-08)	[0..4095]⇒ [0.00E-3A..1.61E-3A]
EVHSHeatVolt	*Measure voltage of Evaporator Heat Switch heater*	ADCv=p1*V_L+p0	p1=3.93E+4 p0=0.	p1=39323.4 (0.15) p0=-4.94 (0.056)	[0.00E-3V..6.47E-1V]⇒ [0..25433]
SPHSHeatVolt	*Measure voltage of Sorption Pump Heat Switch heater*			p1=39315.8 (0.14) p0=-5.945 (0.052)	[0.00E-3V..6.47E-1V]⇒ [0..25431]
TCheaterCur	*Set current of Thermal Control Heater*	I_L=p1*DAC+p0	p1=1.22E-8A p0=0. A	p1=1.216607E-08 (7.8E-15) p0=-7.09E-09 (1.9E-11)	[0..4095]⇒ [0.00E-5A..4.98E-5A]
TCheaterVolt	*Measure voltage of Thermal Control Heater*	ADCv=p1*V_L+p0	p1=1.05E+5 p0=0.	p1=104810.2 (0.54) p0=4.70 (0.092)	[0.00E-3V..2.99E-1V]⇒ [0..31330]
SPHeaterCur	*Set current of Sorption Pump Heater*	I_L=p1*DAC+p0	p1=1.22E-5A p0=0. A	p1=1.21532E-05 (1.4E-11) p0=-2.254E-05 (2.4E-08)	[0..3178]⇒ [0.00E-3A..38.6E-3A] [3178..4095]⇒ [38.6E-3A] (see Note[5])
SPHeaterVolt	*Measure voltage of Sorption Pump Heater*	ADCv=p1*V_L+p0	p1=1.64E+3 p0=0.	p1=1630.112 (0.0054) p0=-3.88 (0.046)	[0.00E-3V..15.51V]⇒ [0..25291]

Table 36 Heater transfer functions

[3] The theoretical slope and intercept values are ideal computations derived from the installed nominal circuit component values. They are given to 0.1% relative precision. They do not take component spread and temperature variation into account. The unit used for the p0 parameter of zero offset circuits is arbitrary.

[4] The expressed ADC values are indicative and result from raw calculation of the range boundaries. They do not imply precision to the last digit.

[5] The SPheater saturation occurs at a point which depends on the load resistance (R_L), the harness resistance and the ±9V supply values. The saturation point indicated here was observed at R_L=408 Ω, no harness resistance, and nominal ±9V supplies.

7.1.7 FpuTemp transfer functions (1/2)

Parameter Name	Usage	Transfer function	Nominal value[6] (gain resistance)	QM1 25℃ values (acceptance range)	QM1 25℃ full range variation
T_CPHP (FpuTemp01)	*Measure Cryo-cooler Sorption Pump temperature*	ADCi= p1/R_L+p0	p1=-3.60E+06 p0=0. (Rg=54.9kΩ)	p1=-3.675E+06 p0=133. (90% subrange: [1.7kΩ..284Ω])	[1.5K..50K]⇒ [1.7kΩ..127Ω]⇒ [-1992..-27329]
T_SCST (FpuTemp13)	*Measure Spectrometer Calibrator Flange temperature*			p1=-3.643E+06 p0=34.3 (70% subrange: [2.9kΩ..959Ω])	[1K..50K]⇒ [2.9kΩ..127Ω]⇒ [-1160..-29032]
T_CPHS (FpuTemp02)	*Measure Cryo-cooler Sorption Pump Heat Switch temperature*		p1=-5.41E+06 p0=0. (Rg=82.5kΩ)	p1=-5.542E+06 p0=181. (90% subrange: [1.7kΩ..337Ω])	[1.5K..25K]⇒ [1.7kΩ..186Ω]⇒ [-3041..-28377]
T_CEHS (FpuTemp03)	*Measure Cryo-cooler Evaporator Heat Switch temperature*			p1=-5.523E+06 p0=176. (90% subrange: [1.7kΩ..337Ω])	
T_CSHT (FpuTemp04)	*Measure Cryo-cooler Thermal Shunt temperature*		p1=-8.52E+06 p0=0. (Rg=130kΩ)	p1=-9.025E+06 p0=262. (90% subrange: [1.7kΩ..454Ω])	[1.5K..10K]⇒ [1.7kΩ..316Ω]⇒ [-5027..-27066]
T_SLO (FpuTemp06)	*Measure Spectrometer Detector Box temperature*			p1=-8.42E+06 p0=25. (25% subrange: [2.9kΩ..2254Ω])	[1K..10K]⇒ [2.9kΩ..316Ω]⇒ [-2860..-26968]
T_PLO (FpuTemp07)	*Measure Photometer Detector Box temperature*			p1=-8.60E+06 p0=24. (27% subrange: [2.9kΩ..2254Ω])	
T_SOB (FpuTemp05)	*Measure SPIRE Optical Bench temperature*		p1=-1.25E+06 p0=0. (Rg=19.1kΩ)	p1=-1.30E+06 p0=70. (40% subrange: [779Ω..482Ω])	[3K..300K]⇒ [779Ω..38Ω]⇒ [-1514..-32768sat]
T_SUB (FpuTemp08)	*Measure Optical Sub Bench temperature*		p1=-2.12E+06 p0=0. (Rg=32.4kΩ)	p1=-2.213E+06 p0=92. (60% subrange: [779Ω..361Ω])	[3K..100K]⇒ [779Ω..82Ω]⇒ [-2650..-26186]
T_BAF (FpuTemp09)	*Measure FPU Input Baffle temperature*			p1=-2.230E+06 p0=85. (50% subrange: [779Ω..430Ω])	
T_FTSS (FpuTemp14)	*Measure SMEC/SOB I/F temperature*			p1=-2.251E+06 p0=135. (70% subrange: [779Ω..291Ω])	
T_BSMS (FpuTemp10)	*Measure BSM/SOB I/F temperature*		p1=-2.90E+06 p0=0. (Rg=44.2kΩ)	p1=-2.835E+06 p0=10. (40% subrange: [779Ω..505Ω])	[3K..80K]⇒ [779Ω..95Ω]⇒ [-3644..-30802]
T_SCL2 (FpuTemp11)	*Measure Spectrometer Calibrator 2% temperature*			p1=-3.22E+06 p0=620. (40% subrange: [316Ω..228Ω])	[10K..80K]⇒ [316Ω..95Ω]⇒ [-9145..-30212]
T_SCL4 (FpuTemp12)	*Measure Spectrometer Calibrator 4% temperature*			p1=-3.25E+06 p0=579. (40% subrange: [316Ω..228Ω])	

Table 37 FpuTemp transfer functions (1/2)

[6] The channel theoretical Y_L to ADC parameter is p1= -(65536/10)*Rg*V_L, where Rg is the current to voltage gain resistance and V_L is the probe voltage bias (V_L =10 mV in this calculation).

7.1.8 FpuTemp transfer functions (2/2)

Parameter Name	Usage	Transfer function	Nominal value (gain resistance)	QM1 25℃ values (acceptance range)	QM1 25℃ full range variation
T_FTSM (FpuTemp15)	*Measure SMEC mechanism temperature*	ADCi= p1/R_L+p0	p1=-6.55E+06 p0=0. (Rg=100kΩ)	p1=-6.94E+06 p0=306. (70% subrange: [779Ω..384Ω])	[3K..20K]⇒ [779Ω..215Ω]⇒ [-8369..-30507]
T_BSMM (FpuTemp16)	*Measure BSM mechanism temperature*			p1=-6.86E+06 p0=308. (70% subrange: [779Ω..384Ω])	

Table 38 FpuTemp transfer functions (2/2)

7.1.9 SubKTemp transfer function

Parameter Name	Usage	Transfer function	Nominal value	QM1 25℃ values (acceptance range)	QM1 25℃ full range variation
T_CEV	*Measure Cryo-Cooler Evaporator temperature*	ADCv= p1*R_L+p0	p1=-3.76E-01 p0=32768.	p1=-3.261E-01 p0=32008. (95% subrange: [150kΩ..3310Ω])	[300mK..20K]⇒ [150kΩ..300Ω]⇒ [-16900..31170]

Table 39 SubKTemp transfer functions

8 Digital tests

This section gives the result of the digital tests.

8.1 Performed tests

The following items were specifically tested on the QM1 model:

- Power On reset behaviour, and corresponding initial values for external signals.
- Command interface protocol, format and boundary conditions.
- Access to registers and resources, according to AD 7, §6.2, "Programming model".
- Data frame protocol, format, content and frequency.

8.2 Method

A dedicated DPU master interface was developed in a specific FPGA-based USB device, under control of a PC host program (see §4.1, Figure 35 for a conceptual setup diagram). The FPGA design is instrumented to measure the SCU command execution times (5 µs resolution) and the data frame sequence timing parameters (frame-to-frame and word-to-word intervals, 12.5 ns resolution).

8.3 Data frame tests

8.3.1 Data frame sequence, Test Pattern format (80 Hz)

The following test log extract gives the measurements performed on the data interface in a typical session, where a sequence of 31 "test pattern" frames @80 Hz was selected. The exact expected bit-per-bit format is checked during test execution. The log gives the time intervals measured by the FPGA interface and the Time Stamp value produced in each frame.

```
dpu.exe> ################################################################
dpu.exe> Test frame transfer
dpu.exe> ################################################################
dpu.exe> Do TestPattern   : default is no        (y/n/q) ? y
dpu.exe> Show content     : default is yes       (y/n/q) ? y
dpu.exe> Show timings     : default is no        (y/n/q) ? y
dpu.exe> Do fifo debug    : default is no        (y/n/q) ?
dpu.exe> Echo commands    : default is no        (y/n/q) ?
dpu.exe> Log frame data   : default is no        (y/n/q) ?
dpu.exe> Do CmdIf access  : default is no        (y/n/q) ?
dpu.exe> FrameRate        : default is 256       (80hz/i with 1<=i<=256 or q) ? 1
dpu.exe> SeqLength        : default is 4         (0 for infinit or 1<=i<=31 or q) ? 31
dpu.exe> Initiate frame transfer
dpu.exe> WordDeltaTime=681.96us (1: 0) Receive LENGTH=0000000000011110(0x001E)
dpu.exe> WordDeltaTime=  7.17us (1: 1) Receive HEADER=0000000000100001(0x0021)
dpu.exe> WordDeltaTime= 70.80us (1: 2) Receive FRDATA=1010101010101010(0xAAAA)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (1: 3) Receive FRDATA=0101010101010100(0x5554)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (1: 4) Receive FRDATA=1010101010101000(0xAAA8)=RANDOM
```

```
dpu.exe> WordDeltaTime= 70.79us (1: 5) Receive FRDATA=0101010101010000(0x5550)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (1: 6) Receive FRDATA=1010101010100000(0xAAA0)=RANDOM
dpu.exe> WordDeltaTime= 70.80us (1: 7) Receive FRDATA=0101010101000001(0x5541)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (1: 8) Receive FRDATA=1010101010000010(0xAA82)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (1: 9) Receive FRDATA=0101010100000101(0x5505)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (1:10) Receive FRDATA=1010101000001010(0xAA0A)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (1:11) Receive FRDATA=0101010000010100(0x5414)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (1:12) Receive FRDATA=1010100000101000(0xA828)=RANDOM
dpu.exe> WordDeltaTime= 70.80us (1:13) Receive FRDATA=0101000001010000(0x5050)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (1:14) Receive FRDATA=1010000010100000(0xA0A0)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (1:15) Receive FRDATA=0100000101000001(0x4141)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (1:16) Receive FRDATA=1000001010000011(0x8283)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (1:17) Receive FRDATA=0000010100000111(0x0507)=RANDOM
dpu.exe> WordDeltaTime= 70.80us (1:18) Receive FRDATA=0000101000001110(0x0A0E)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (1:19) Receive FRDATA=0001010000011101(0x141D)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (1:20) Receive FRDATA=0010100000111010(0x283A)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (1:21) Receive FRDATA=0101000001110101(0x5075)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (1:22) Receive FRDATA=1010000011101010(0xA0EA)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (1:23) Receive FRDATA=0100000111010100(0x41D4)=RANDOM
dpu.exe> WordDeltaTime= 70.80us (1:24) Receive FRDATA=1000001110101001(0x83A9)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (1:25) Receive FRDATA=0000011101010010(0x0752)=RANDOM
dpu.exe> WordDeltaTime=  7.17us (1:26) Receive STATUS=0000000000000000(0x0000)
dpu.exe> WordDeltaTime=  7.17us (1:27) Receive TIMERH=0000000000000000(0x0000)
dpu.exe> WordDeltaTime=  7.17us (1:28) Receive TIMERL=0001010100110011(0x1533)
dpu.exe> WordDeltaTime=  7.17us (1:29) Receive FRLPAR=0111011011110110(0x76F6)
dpu.exe> FrameDuration=1.73ms FrameDeltaTime=798.68ms(1.2521hz)
dpu.exe> WordDeltaTime=117.43us (2: 0) Receive LENGTH=0000000000011110(0x001E)
dpu.exe> WordDeltaTime=  7.19us (2: 1) Receive HEADER=0000000000100001(0x0021)
dpu.exe> WordDeltaTime= 70.79us (2: 2) Receive FRDATA=0000111010100100(0x0EA4)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2: 3) Receive FRDATA=0001110101001000(0x1D48)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2: 4) Receive FRDATA=0011101010010000(0x3A90)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2: 5) Receive FRDATA=0111010100100001(0x7521)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2: 6) Receive FRDATA=1110101001000010(0xEA42)=RANDOM
dpu.exe> WordDeltaTime= 70.80us (2: 7) Receive FRDATA=1101010010000100(0xD484)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2: 8) Receive FRDATA=1010100100001001(0xA909)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2: 9) Receive FRDATA=0101001000010010(0x5212)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2:10) Receive FRDATA=1010010000100100(0xA424)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2:11) Receive FRDATA=0100100001001001(0x4849)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2:12) Receive FRDATA=1001000010010010(0x9092)=RANDOM
dpu.exe> WordDeltaTime= 70.80us (2:13) Receive FRDATA=0010000100100100(0x2124)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2:14) Receive FRDATA=0100001001001000(0x4248)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2:15) Receive FRDATA=1000010010010000(0x8490)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2:16) Receive FRDATA=0000100100100001(0x0921)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2:17) Receive FRDATA=0001001001000010(0x1242)=RANDOM
dpu.exe> WordDeltaTime= 70.80us (2:18) Receive FRDATA=0010010010000101(0x2485)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2:19) Receive FRDATA=0100100100001010(0x490A)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2:20) Receive FRDATA=1001001000010100(0x9214)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2:21) Receive FRDATA=0010010000101000(0x2428)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2:22) Receive FRDATA=0100100001010001(0x4851)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2:23) Receive FRDATA=1001000010100011(0x90A3)=RANDOM
dpu.exe> WordDeltaTime= 70.80us (2:24) Receive FRDATA=0010000101000110(0x2146)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (2:25) Receive FRDATA=0100001010001100(0x428C)=RANDOM
dpu.exe> WordDeltaTime=  7.17us (2:26) Receive STATUS=0000000000000000(0x0000)
dpu.exe> WordDeltaTime=  7.17us (2:27) Receive TIMERH=0000000000000000(0x0000)
dpu.exe> WordDeltaTime=  7.17us (2:28) Receive TIMERL=0010010001110110(0x2476)
dpu.exe> WordDeltaTime=  7.17us (2:29) Receive FRLPAR=0101110100100010(0x5D22)
dpu.exe> FrameDeltaCycles = 3907 <=> 12.50ms (79.9846hz) for a DPUCLK=312.5kHz
```



```
dpu.exe> FrameDuration=1.73ms FrameDeltaTime=12.50ms(79.9834hz)
[Intermediate frames (#3 to #30) removed…]

dpu.exe> FrameDuration=1.73ms FrameDeltaTime=12.50ms(79.9834hz)
dpu.exe> WordDeltaTime=117.43us (31: 0) Receive LENGTH=0000000000011110(0x001E)
dpu.exe> WordDeltaTime=  7.17us (31: 1) Receive HEADER=0000000000100001(0x0021)
dpu.exe> WordDeltaTime= 70.79us (31: 2) Receive FRDATA=0011101010100011(0x3AA3)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31: 3) Receive FRDATA=0111010101000111(0x7547)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31: 4) Receive FRDATA=1110101010001110(0xEA8E)=RANDOM
dpu.exe> WordDeltaTime= 70.80us (31: 5) Receive FRDATA=1101010100011101(0xD51D)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31: 6) Receive FRDATA=1010101000111010(0xAA3A)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31: 7) Receive FRDATA=0101010001110100(0x5474)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31: 8) Receive FRDATA=1010100011101000(0xA8E8)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31: 9) Receive FRDATA=0101000111010000(0x51D0)=RANDOM
dpu.exe> WordDeltaTime= 70.80us (31:10) Receive FRDATA=1010001110100000(0xA3A0)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31:11) Receive FRDATA=0100011101000001(0x4741)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31:12) Receive FRDATA=1000111010000011(0x8E83)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31:13) Receive FRDATA=0001110100000111(0x1D07)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31:14) Receive FRDATA=0011101000001111(0x3A0F)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31:15) Receive FRDATA=0111010000011110(0x741E)=RANDOM
dpu.exe> WordDeltaTime= 70.80us (31:16) Receive FRDATA=1110100000111101(0xE83D)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31:17) Receive FRDATA=1101000001111011(0xD07B)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31:18) Receive FRDATA=1010000011110110(0xA0F6)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31:19) Receive FRDATA=0100000111101101(0x41ED)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31:20) Receive FRDATA=1000001111011010(0x83DA)=RANDOM
dpu.exe> WordDeltaTime= 70.80us (31:21) Receive FRDATA=0000011110110100(0x07B4)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31:22) Receive FRDATA=0000111101101000(0x0F68)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31:23) Receive FRDATA=0001111011010001(0x1ED1)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31:24) Receive FRDATA=0011110110100011(0x3DA3)=RANDOM
dpu.exe> WordDeltaTime= 70.79us (31:25) Receive FRDATA=0111101101000111(0x7B47)=RANDOM
dpu.exe> WordDeltaTime=  7.17us (31:26) Receive STATUS=0000000000000000(0x0000)
dpu.exe> WordDeltaTime=  7.19us (31:27) Receive TIMERH=0000000000000001(0x0001)
dpu.exe> WordDeltaTime=  7.17us (31:28) Receive TIMERL=1101111100001111(0xDF0F)
dpu.exe> WordDeltaTime=  7.17us (31:29) Receive FRLPAR=1001101100101010(0x9B2A)
dpu.exe> FrameDeltaCycles = 3907 <=> 12.50ms (79.9846hz) for a DPUCLK=312.5kHz
dpu.exe> FrameDuration=1.73ms FrameDeltaTime=12.50ms(79.9834hz)
```

8.3.2 Data frame sequence, Normal format (40 Hz)

The following test log extract gives the measurements performed on the data interface in a typical session, where a sequence of 10 "Normal" frames @40 Hz was selected. The DAC default value for Calib/Heater channels is specified. The SubKTemp and FpuTemp probes are set in the "Off" position and left open. The analogue parameters equivalent voltage is calculated. Note that the position of the TCHeatVolt parameter is not consistent with AD7 (see QM1 frame format in §9.1).

```
dpu.exe> ################################################################
dpu.exe> Test frame transfer
dpu.exe> ################################################################
dpu.exe> Do TestPattern   : default is yes       (y/n/q) ? n
dpu.exe> Show content     : default is yes       (y/n/q) ?
dpu.exe> Show timings     : default is yes       (y/n/q) ?
dpu.exe> Do fifo debug    : default is no        (y/n/q) ?
dpu.exe> Echo commands    : default is no        (y/n/q) ?
dpu.exe> Log frame data   : default is no        (y/n/q) ?
dpu.exe> Do CmdIf access  : default is no        (y/n/q) ?
dpu.exe> Data precision   : default is 500       (i>0 or q) ?
dpu.exe> FrameRate        : default is 1         (80hz/i with 1<=i<=256 or q) ? 2
```

```
dpu.exe> SeqLength        : default is 31        (0 for infinit or 1<=i<=31 or q) ? 10
dpu.exe> Conv/Measure     : default is 1         (1/2/4/8 or q) ?
dpu.exe> Set SubK OFF     : default is no        (y/n/q) ?
dpu.exe> Temp num off     : default is all       (?/a/q) ?
dpu.exe> Set all temp OFF with no load
dpu.exe> Wait temp stabilisation (2s)
dpu.exe> Set CalibraV1 DAC to 0
dpu.exe> Set CalibraV2 DAC to 500
dpu.exe> Set CalibraV3 DAC to 1000
dpu.exe> Set LHeaterV1 DAC to 1500
dpu.exe> Set LHeaterV2 DAC to 2000
dpu.exe> Set LHeaterV3 DAC to 2500
dpu.exe> Set HHeaterV1 DAC to 3000
dpu.exe> Initiate frame transfer
dpu.exe> WordDeltaTime=165.43us (1: 0) Receive LENGTH=0000000000011110(0x001E)
dpu.exe> WordDeltaTime=  7.19us (1: 1) Receive HEADER=0000000000100000(0x0020)
dpu.exe> WordDeltaTime= 70.79us (1: 2) Receive FRDATA=1111111111111011(0xFFFB)=-0.000763V=FpuTemp01=T_CPHP
dpu.exe> WordDeltaTime= 70.79us (1: 3) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp02=T_CPHS
dpu.exe> WordDeltaTime= 70.79us (1: 4) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp03=T_CEHS
dpu.exe> WordDeltaTime= 70.79us (1: 5) Receive FRDATA=0000000000000001(0x0001)=+0.000153V=FpuTemp04=T_CSHT
dpu.exe> WordDeltaTime= 70.80us (1: 6) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp05=T_SOB
dpu.exe> WordDeltaTime= 70.79us (1: 7) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp06=T_SLO
dpu.exe> WordDeltaTime= 70.79us (1: 8) Receive FRDATA=1111111111111011(0xFFFB)=-0.000763V=FpuTemp07=T_PLO
dpu.exe> WordDeltaTime= 70.79us (1: 9) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp08=T_SUB
dpu.exe> WordDeltaTime= 70.79us (1:10) Receive FRDATA=0000000000000001(0x0001)=+0.000153V=FpuTemp09=T_BAF
dpu.exe> WordDeltaTime= 70.79us (1:11) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp10=T_BSMS
dpu.exe> WordDeltaTime= 70.80us (1:12) Receive FRDATA=1111111111111111(0xFFFF)=-0.000153V=FpuTemp11=T_SCL2
dpu.exe> WordDeltaTime= 70.79us (1:13) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp12=T_SCL4
dpu.exe> WordDeltaTime= 70.79us (1:14) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp13=T_SCST
dpu.exe> WordDeltaTime= 70.79us (1:15) Receive FRDATA=1111111111111111(0xFFFF)=-0.000153V=FpuTemp14=T_FTSS
dpu.exe> WordDeltaTime= 70.79us (1:16) Receive FRDATA=1111111111111111(0xFFFF)=-0.000153V=FpuTemp15=T_FTSM
dpu.exe> WordDeltaTime= 70.80us (1:17) Receive FRDATA=1111111111111111(0xFFFF)=-0.000153V=FpuTemp16=T_BSMM
dpu.exe> WordDeltaTime= 70.79us (1:18) Receive FRDATA=1011111001100100(0xBE64)=-2.562866V=SubKTempP=T_CEV
dpu.exe> WordDeltaTime= 70.79us (1:19) Receive
FRDATA=0100101010110101(0x4AB5)=+2.918243V=LHeaterV3=TCheaterVolt
dpu.exe> WordDeltaTime= 70.79us (1:20) Receive FRDATA=0000000000010101(0x0015)=+0.003204V=CalibraI1=PhCalCur
dpu.exe> WordDeltaTime= 70.79us (1:21) Receive FRDATA=0000000000000100(0x0004)=+0.000610V=CalibraV1=PhCalVolt
dpu.exe> WordDeltaTime= 70.79us (1:22) Receive FRDATA=0000111011100111(0x0EE7)=+0.582123V=CalibraI2=SCal2Cur
dpu.exe> WordDeltaTime= 70.80us (1:23) Receive FRDATA=0000110110000001(0x0D81)=+0.527496V=CalibraV2=Scal2Volt
dpu.exe> WordDeltaTime= 70.79us (1:24) Receive FRDATA=0001110111101011(0x1DEB)=+1.168671V=CalibraI3=Scal4Cur
dpu.exe> WordDeltaTime= 70.79us (1:25) Receive FRDATA=0001101100010111(0x1B17)=+1.058197V=CalibraV3=Scal4Volt
dpu.exe> WordDeltaTime=  7.17us (1:26) Receive STATUS=0000000000000000(0x0000)
dpu.exe> WordDeltaTime=  7.17us (1:27) Receive TIMERH=0000000000000000(0x0000)
dpu.exe> WordDeltaTime=  7.17us (1:28) Receive TIMERL=0001010100110000(0x1530)
dpu.exe> WordDeltaTime=  7.17us (1:29) Receive FRLPAR=1110010001010100(0xE454)
dpu.exe> FrameDuration=1.73ms FrameDeltaTime=5329.16ms(0.1876hz)
dpu.exe> WordDeltaTime=332.05us (2: 0) Receive LENGTH=0000000000011110(0x001E)
dpu.exe> WordDeltaTime=  7.17us (2: 1) Receive HEADER=0000000000100000(0x0020)
dpu.exe> WordDeltaTime= 70.79us (2: 2) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp01=T_CPHP
dpu.exe> WordDeltaTime= 70.79us (2: 3) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp02=T_CPHS
dpu.exe> WordDeltaTime= 70.79us (2: 4) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp03=T_CEHS
dpu.exe> WordDeltaTime= 70.79us (2: 5) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp04=T_CSHT
dpu.exe> WordDeltaTime= 70.80us (2: 6) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp05=T_SOB
dpu.exe> WordDeltaTime= 70.79us (2: 7) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp06=T_SLO
dpu.exe> WordDeltaTime= 70.79us (2: 8) Receive FRDATA=1111111111111111(0xFFFF)=-0.000153V=FpuTemp07=T_PLO
dpu.exe> WordDeltaTime= 70.79us (2: 9) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp08=T_SUB
dpu.exe> WordDeltaTime= 70.79us (2:10) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp09=T_BAF
```



```
dpu.exe> WordDeltaTime= 70.80us (2:11) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp10=T_BSMS
dpu.exe> WordDeltaTime= 70.79us (2:12) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp11=T_SCL2
dpu.exe> WordDeltaTime= 70.79us (2:13) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp12=T_SCL4
dpu.exe> WordDeltaTime= 70.79us (2:14) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp13=T_SCST
dpu.exe> WordDeltaTime= 70.79us (2:15) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp14=T_FTSS
dpu.exe> WordDeltaTime= 70.79us (2:16) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp15=T_FTSM
dpu.exe> WordDeltaTime= 70.80us (2:17) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp16=T_BSMM
dpu.exe> WordDeltaTime= 70.79us (2:18) Receive FRDATA=1011111001101000(0xBE68)=-2.562256V=SubKTempP=T_CEV
dpu.exe> WordDeltaTime= 70.79us (2:19) Receive
FRDATA=0100101010110101(0x4AB5)=+2.918243V=LHeaterV3=TCheaterVolt
dpu.exe> WordDeltaTime= 70.79us (2:20) Receive FRDATA=0000000000011000(0x0018)=+0.003662V=CalibraI1=PhCalCur
dpu.exe> WordDeltaTime= 70.79us (2:21) Receive FRDATA=0000000000000100(0x0004)=+0.000610V=CalibraV1=PhCalVolt
dpu.exe> WordDeltaTime= 70.80us (2:22) Receive FRDATA=0000111011100111(0x0EE7)=+0.582123V=CalibraI2=SCal2Cur
dpu.exe> WordDeltaTime= 70.79us (2:23) Receive FRDATA=0000110110000001(0x0D81)=+0.527496V=CalibraV2=Scal2Volt
dpu.exe> WordDeltaTime= 70.79us (2:24) Receive FRDATA=0001110111101010(0x1DEA)=+1.168518V=CalibraI3=Scal4Cur
dpu.exe> WordDeltaTime= 70.79us (2:25) Receive FRDATA=0001101100010110(0x1B16)=+1.058044V=CalibraV3=Scal4Volt
dpu.exe> WordDeltaTime=  7.17us (2:26) Receive STATUS=0000000000000000(0x0000)
dpu.exe> WordDeltaTime=  7.17us (2:27) Receive TIMERH=0000000000000000(0x0000)
dpu.exe> WordDeltaTime=  7.17us (2:28) Receive TIMERL=0011001110110110(0x33B6)
dpu.exe> WordDeltaTime=  7.19us (2:29) Receive FRLPAR=1100001011010001(0xC2D1)
dpu.exe> FrameDeltaCycles = 7814 <=> 25.00ms (39.9923hz) for a DPUCLK=312.5kHz
dpu.exe> FrameDuration=1.73ms FrameDeltaTime=25.01ms(39.9917hz)
[Intermediate frames (#3 to #9) removed…]

dpu.exe> FrameDuration=1.73ms FrameDeltaTime=25.01ms(39.9917hz)
dpu.exe> WordDeltaTime=332.04us (10: 0) Receive LENGTH=0000000000011110(0x001E)
dpu.exe> WordDeltaTime=  7.19us (10: 1) Receive HEADER=0000000000100000(0x0020)
dpu.exe> WordDeltaTime= 70.79us (10: 2) Receive FRDATA=0000000000000010(0x0002)=+0.000305V=FpuTemp01=T_CPHP
dpu.exe> WordDeltaTime= 70.79us (10: 3) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp02=T_CPHS
dpu.exe> WordDeltaTime= 70.79us (10: 4) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp03=T_CEHS
dpu.exe> WordDeltaTime= 70.79us (10: 5) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp04=T_CSHT
dpu.exe> WordDeltaTime= 70.80us (10: 6) Receive FRDATA=1111111111111100(0xFFFC)=-0.000610V=FpuTemp05=T_SOB
dpu.exe> WordDeltaTime= 70.79us (10: 7) Receive FRDATA=1111111111111111(0xFFFF)=-0.000153V=FpuTemp06=T_SLO
dpu.exe> WordDeltaTime= 70.79us (10: 8) Receive FRDATA=1111111111111111(0xFFFF)=-0.000153V=FpuTemp07=T_PLO
dpu.exe> WordDeltaTime= 70.79us (10: 9) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp08=T_SUB
dpu.exe> WordDeltaTime= 70.79us (10:10) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp09=T_BAF
dpu.exe> WordDeltaTime= 70.79us (10:11) Receive FRDATA=1111111111111011(0xFFFB)=-0.000763V=FpuTemp10=T_BSMS
dpu.exe> WordDeltaTime= 70.80us (10:12) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp11=T_SCL2
dpu.exe> WordDeltaTime= 70.79us (10:13) Receive FRDATA=1111111111111111(0xFFFF)=-0.000153V=FpuTemp12=T_SCL4
dpu.exe> WordDeltaTime= 70.79us (10:14) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp13=T_SCST
dpu.exe> WordDeltaTime= 70.79us (10:15) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp14=T_FTSS
dpu.exe> WordDeltaTime= 70.79us (10:16) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp15=T_FTSM
dpu.exe> WordDeltaTime= 70.80us (10:17) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp16=T_BSMM
dpu.exe> WordDeltaTime= 70.79us (10:18) Receive FRDATA=1011111001100110(0xBE66)=-2.562561V=SubKTempP=T_CEV
dpu.exe> WordDeltaTime= 70.79us (10:19) Receive
FRDATA=0100101010110101(0x4AB5)=+2.918243V=LHeaterV3=TCheaterVolt
dpu.exe> WordDeltaTime= 70.79us (10:20) Receive FRDATA=0000000000010000(0x0010)=+0.002441V=CalibraI1=PhCalCur
dpu.exe> WordDeltaTime= 70.79us (10:21) Receive FRDATA=0000000000000011(0x0003)=+0.000458V=CalibraV1=PhCalVolt
dpu.exe> WordDeltaTime= 70.79us (10:22) Receive FRDATA=0000111011100110(0x0EE6)=+0.581970V=CalibraI2=SCal2Cur
dpu.exe> WordDeltaTime= 70.80us (10:23) Receive FRDATA=0000110110000001(0x0D81)=+0.527496V=CalibraV2=Scal2Volt
dpu.exe> WordDeltaTime= 70.79us (10:24) Receive FRDATA=0001110111101010(0x1DEA)=+1.168518V=CalibraI3=Scal4Cur
dpu.exe> WordDeltaTime= 70.79us (10:25) Receive FRDATA=0001101100010110(0x1B16)=+1.058044V=CalibraV3=Scal4Volt
dpu.exe> WordDeltaTime=  7.17us (10:26) Receive STATUS=0000000000000000(0x0000)
dpu.exe> WordDeltaTime=  7.17us (10:27) Receive TIMERH=0000000000000001(0x0001)
dpu.exe> WordDeltaTime=  7.17us (10:28) Receive TIMERL=0010011111100111(0x27E7)
dpu.exe> WordDeltaTime=  7.19us (10:29) Receive FRLPAR=1101011010000100(0xD684)
dpu.exe> FrameDeltaCycles = 7814 <=> 25.00ms (39.9923hz) for a DPUCLK=312.5kHz
```

```
dpu.exe> FrameDuration=1.73ms FrameDeltaTime=25.01ms(39.9917hz)
dpu.exe>
dpu.exe> 10 frames received (no error, see "D:\test_olga\tmp\stb2dpu_Dat.bit" for detail)
dpu.exe>
```

8.3.3 Data frame sequence, Normal format (0.3125 Hz)

The following test log extract gives the result of a sequence of 4 “Normal” frames @0.3125 Hz. All other settings are the same as in §8.3.2.

```
dpu.exe> ################################################################
dpu.exe> Test frame transfer
dpu.exe> ################################################################
dpu.exe> Do TestPattern   : default is no       (y/n/q) ? n
dpu.exe> Show content     : default is yes      (y/n/q) ?
dpu.exe> Show timings     : default is yes      (y/n/q) ?
dpu.exe> Do fifo debug    : default is no       (y/n/q) ?
dpu.exe> Echo commands    : default is no       (y/n/q) ?
dpu.exe> Log frame data   : default is no       (y/n/q) ?
dpu.exe> Do CmdIf access  : default is no       (y/n/q) ?
dpu.exe> Data precision   : default is 500      (i>0 or q) ?
dpu.exe> FrameRate        : default is 2        (80hz/i with 1<=i<=256 or q) ? 256
dpu.exe> SeqLength        : default is 10       (0 for infinit or 1<=i<=31 or q) ? 4
dpu.exe> Conv/Measure     : default is 1        (1/2/4/8 or q) ?
dpu.exe> Set SubK OFF     : default is no       (y/n/q) ? n
dpu.exe> Temp num off     : default is all      (?/a/q) ?
dpu.exe> Set all temp OFF with no load
dpu.exe> Wait temp stabilisation (2s)
dpu.exe> Set CalibraV1 DAC to 0
dpu.exe> Set CalibraV2 DAC to 500
dpu.exe> Set CalibraV3 DAC to 1000
dpu.exe> Set LHeaterV1 DAC to 1500
dpu.exe> Set LHeaterV2 DAC to 2000
dpu.exe> Set LHeaterV3 DAC to 2500
dpu.exe> Set HHeaterV1 DAC to 3000
dpu.exe> Initiate frame transfer
dpu.exe> WordDeltaTime=778.91us (1: 0) Receive LENGTH=0000000000011110(0x001E)
dpu.exe> WordDeltaTime=  7.17us (1: 1) Receive HEADER=0000000000100000(0x0020)
dpu.exe> WordDeltaTime= 70.79us (1: 2) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp01=T_CPHP
dpu.exe> WordDeltaTime= 70.80us (1: 3) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp02=T_CPHS
dpu.exe> WordDeltaTime= 70.79us (1: 4) Receive FRDATA=1111111111111100(0xFFFC)=-0.000610V=FpuTemp03=T_CEHS
dpu.exe> WordDeltaTime= 70.79us (1: 5) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp04=T_CSHT
dpu.exe> WordDeltaTime= 70.79us (1: 6) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp05=T_SOB
dpu.exe> WordDeltaTime= 70.79us (1: 7) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp06=T_SLO
dpu.exe> WordDeltaTime= 70.79us (1: 8) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp07=T_PLO
dpu.exe> WordDeltaTime= 70.80us (1: 9) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp08=T_SUB
dpu.exe> WordDeltaTime= 70.79us (1:10) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp09=T_BAF
dpu.exe> WordDeltaTime= 70.79us (1:11) Receive FRDATA=1111111111111100(0xFFFC)=-0.000610V=FpuTemp10=T_BSMS
dpu.exe> WordDeltaTime= 70.79us (1:12) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp11=T_SCL2
dpu.exe> WordDeltaTime= 70.79us (1:13) Receive FRDATA=1111111111111111(0xFFFF)=-0.000153V=FpuTemp12=T_SCL4
dpu.exe> WordDeltaTime= 70.79us (1:14) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp13=T_SCST
dpu.exe> WordDeltaTime= 70.80us (1:15) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp14=T_FTSS
dpu.exe> WordDeltaTime= 70.79us (1:16) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp15=T_FTSM
dpu.exe> WordDeltaTime= 70.79us (1:17) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp16=T_BSMM
dpu.exe> WordDeltaTime= 70.79us (1:18) Receive FRDATA=1011111001100111(0xBE67)=-2.562408V=SubKTempP=T_CEV
dpu.exe> WordDeltaTime= 70.79us (1:19) Receive
FRDATA=0100101010110110(0x4AB6)=+2.918396V=LHeaterV3=TCheaterVolt
```



```
dpu.exe> WordDeltaTime= 70.80us (1:20) Receive FRDATA=0000000000011001(0x0019)=+0.003815V=CalibraI1=PhCalCur
dpu.exe> WordDeltaTime= 70.79us (1:21) Receive FRDATA=0000000000000110(0x0006)=+0.000916V=CalibraV1=PhCalVolt
dpu.exe> WordDeltaTime= 70.79us (1:22) Receive FRDATA=0000111011100110(0x0EE6)=+0.581970V=CalibraI2=SCal2Cur
dpu.exe> WordDeltaTime= 70.79us (1:23) Receive FRDATA=0000110110000001(0x0D81)=+0.527496V=CalibraV2=Scal2Volt
dpu.exe> WordDeltaTime= 70.79us (1:24) Receive FRDATA=0001110111101011(0x1DEB)=+1.168671V=CalibraI3=Scal4Cur
dpu.exe> WordDeltaTime= 70.79us (1:25) Receive FRDATA=0001101100010111(0x1B17)=+1.058197V=CalibraV3=Scal4Volt
dpu.exe> WordDeltaTime=  7.19us (1:26) Receive STATUS=0000000000000000(0x0000)
dpu.exe> WordDeltaTime=  7.17us (1:27) Receive TIMERH=0000000000000000(0x0000)
dpu.exe> WordDeltaTime=  7.17us (1:28) Receive TIMERL=0001010100101011(0x152B)
dpu.exe> WordDeltaTime=  7.17us (1:29) Receive FRLPAR=0001101110111111(0x1BBF)
dpu.exe> FrameDuration=1.73ms FrameDeltaTime=2775.51ms(0.3603hz)
dpu.exe> ...WordDeltaTime=776.63us (2: 0) Receive LENGTH=0000000000011110(0x001E)
dpu.exe> WordDeltaTime=  7.17us (2: 1) Receive HEADER=0000000000100000(0x0020)
dpu.exe> WordDeltaTime= 70.79us (2: 2) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp01=T_CPHP
dpu.exe> WordDeltaTime= 70.79us (2: 3) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp02=T_CPHS
dpu.exe> WordDeltaTime= 70.79us (2: 4) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp03=T_CEHS
dpu.exe> WordDeltaTime= 70.80us (2: 5) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp04=T_CSHT
dpu.exe> WordDeltaTime= 70.79us (2: 6) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp05=T_SOB
dpu.exe> WordDeltaTime= 70.79us (2: 7) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp06=T_SLO
dpu.exe> WordDeltaTime= 70.79us (2: 8) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp07=T_PLO
dpu.exe> WordDeltaTime= 70.79us (2: 9) Receive FRDATA=1111111111111111(0xFFFF)=-0.000153V=FpuTemp08=T_SUB
dpu.exe> WordDeltaTime= 70.80us (2:10) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp09=T_BAF
dpu.exe> WordDeltaTime= 70.79us (2:11) Receive FRDATA=1111111111111100(0xFFFC)=-0.000610V=FpuTemp10=T_BSMS
dpu.exe> WordDeltaTime= 70.79us (2:12) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp11=T_SCL2
dpu.exe> WordDeltaTime= 70.79us (2:13) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp12=T_SCL4
dpu.exe> WordDeltaTime= 70.79us (2:14) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp13=T_SCST
dpu.exe> WordDeltaTime= 70.80us (2:15) Receive FRDATA=0000000000000001(0x0001)=+0.000153V=FpuTemp14=T_FTSS
dpu.exe> WordDeltaTime= 70.79us (2:16) Receive FRDATA=1111111111111111(0xFFFF)=-0.000153V=FpuTemp15=T_FTSM
dpu.exe> WordDeltaTime= 70.79us (2:17) Receive FRDATA=1111111111111101(0xFFFD)=-0.000458V=FpuTemp16=T_BSMM
dpu.exe> WordDeltaTime= 70.79us (2:18) Receive FRDATA=1011111001100110(0xBE66)=-2.562561V=SubKTempP=T_CEV
dpu.exe> WordDeltaTime= 70.79us (2:19) Receive
FRDATA=0100101010110110(0x4AB6)=+2.918396V=LHeaterV3=TCheaterVolt
dpu.exe> WordDeltaTime= 70.79us (2:20) Receive FRDATA=0000000000011110(0x001E)=+0.004578V=CalibraI1=PhCalCur
dpu.exe> WordDeltaTime= 70.80us (2:21) Receive FRDATA=0000000000000100(0x0004)=+0.000610V=CalibraV1=PhCalVolt
dpu.exe> WordDeltaTime= 70.79us (2:22) Receive FRDATA=0000111011100110(0x0EE6)=+0.581970V=CalibraI2=SCal2Cur
dpu.exe> WordDeltaTime= 70.79us (2:23) Receive FRDATA=0000110110000001(0x0D81)=+0.527496V=CalibraV2=Scal2Volt
dpu.exe> WordDeltaTime= 70.79us (2:24) Receive FRDATA=0001110111101011(0x1DEB)=+1.168671V=CalibraI3=Scal4Cur
dpu.exe> WordDeltaTime= 70.79us (2:25) Receive FRDATA=0001101100010111(0x1B17)=+1.058197V=CalibraV3=Scal4Volt
dpu.exe> WordDeltaTime=  7.17us (2:26) Receive STATUS=0000000000000000(0x0000)
dpu.exe> WordDeltaTime=  7.17us (2:27) Receive TIMERH=0000000000001111(0x000F)
dpu.exe> WordDeltaTime=  7.19us (2:28) Receive TIMERL=0101100000111100(0x583C)
dpu.exe> WordDeltaTime=  7.17us (2:29) Receive FRLPAR=0101011010100010(0x56A2)
dpu.exe> FrameDeltaCycles = 1000209 <=> 3200.67ms (0.3124hz) for a DPUCLK=312.5kHz
dpu.exe> FrameDuration=1.73ms FrameDeltaTime=3200.67ms(0.3124hz)
[Intermediate frame (#3) removed…]

dpu.exe> FrameDuration=1.73ms FrameDeltaTime=3200.67ms(0.3124hz)
dpu.exe> ...WordDeltaTime=776.63us (4: 0) Receive LENGTH=0000000000011110(0x001E)
dpu.exe> WordDeltaTime=  7.17us (4: 1) Receive HEADER=0000000000100000(0x0020)
dpu.exe> WordDeltaTime= 70.79us (4: 2) Receive FRDATA=1111111111111011(0xFFFB)=-0.000763V=FpuTemp01=T_CPHP
dpu.exe> WordDeltaTime= 70.79us (4: 3) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp02=T_CPHS
dpu.exe> WordDeltaTime= 70.79us (4: 4) Receive FRDATA=0000000000000001(0x0001)=+0.000153V=FpuTemp03=T_CEHS
dpu.exe> WordDeltaTime= 70.80us (4: 5) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp04=T_CSHT
dpu.exe> WordDeltaTime= 70.79us (4: 6) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp05=T_SOB
dpu.exe> WordDeltaTime= 70.79us (4: 7) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp06=T_SLO
dpu.exe> WordDeltaTime= 70.79us (4: 8) Receive FRDATA=1111111111111011(0xFFFB)=-0.000763V=FpuTemp07=T_PLO
dpu.exe> WordDeltaTime= 70.79us (4: 9) Receive FRDATA=1111111111111100(0xFFFC)=-0.000610V=FpuTemp08=T_SUB
```

```
dpu.exe> WordDeltaTime= 70.79us (4:10) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp09=T_BAF
dpu.exe> WordDeltaTime= 70.80us (4:11) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp10=T_BSMS
dpu.exe> WordDeltaTime= 70.79us (4:12) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp11=T_SCL2
dpu.exe> WordDeltaTime= 70.79us (4:13) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp12=T_SCL4
dpu.exe> WordDeltaTime= 70.79us (4:14) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp13=T_SCST
dpu.exe> WordDeltaTime= 70.79us (4:15) Receive FRDATA=1111111111111111(0xFFFF)=-0.000153V=FpuTemp14=T_FTSS
dpu.exe> WordDeltaTime= 70.80us (4:16) Receive FRDATA=1111111111111110(0xFFFE)=-0.000305V=FpuTemp15=T_FTSM
dpu.exe> WordDeltaTime= 70.79us (4:17) Receive FRDATA=0000000000000000(0x0000)=+0.000000V=FpuTemp16=T_BSMM
dpu.exe> WordDeltaTime= 70.79us (4:18) Receive FRDATA=1011111001100110(0xBE66)=-2.562561V=SubKTempP=T_CEV
dpu.exe> WordDeltaTime= 70.79us (4:19) Receive
FRDATA=0100101010110111(0x4AB7)=+2.918549V=LHeaterV3=TCheaterVolt
dpu.exe> WordDeltaTime= 70.79us (4:20) Receive FRDATA=0000000000010111(0x0017)=+0.003510V=CalibraI1=PhCalCur
dpu.exe> WordDeltaTime= 70.80us (4:21) Receive FRDATA=0000000000000101(0x0005)=+0.000763V=CalibraV1=PhCalVolt
dpu.exe> WordDeltaTime= 70.79us (4:22) Receive FRDATA=0000111011100101(0x0EE5)=+0.581818V=CalibraI2=SCal2Cur
dpu.exe> WordDeltaTime= 70.79us (4:23) Receive FRDATA=0000110110000001(0x0D81)=+0.527496V=CalibraV2=Scal2Volt
dpu.exe> WordDeltaTime= 70.79us (4:24) Receive FRDATA=0001110111101101(0x1DED)=+1.168976V=CalibraI3=Scal4Cur
dpu.exe> WordDeltaTime= 70.79us (4:25) Receive FRDATA=0001101100011001(0x1B19)=+1.058502V=CalibraV3=Scal4Volt
dpu.exe> WordDeltaTime=  7.17us (4:26) Receive STATUS=0000000000000000(0x0000)
dpu.exe> WordDeltaTime=  7.19us (4:27) Receive TIMERH=0000000000101101(0x002D)
dpu.exe> WordDeltaTime=  7.17us (4:28) Receive TIMERL=1101111001011110(0xDE5E)
dpu.exe> WordDeltaTime=  7.17us (4:29) Receive FRLPAR=0010111100011100(0x2F1C)
dpu.exe> FrameDeltaCycles = 1000209 <=> 3200.67ms (0.3124hz) for a DPUCLK=312.5kHz
dpu.exe> FrameDuration=1.73ms FrameDeltaTime=3200.67ms(0.3124hz)
dpu.exe>
dpu.exe> 4 frames received (no error, see "D:\test_olga\tmp\stb2dpu_Dat.bit" for detail)
dpu.exe>
```


9 Test coverage

This section checks the QM1 test coverage against the requirements expressed in the AD1 specification document.

9.1 AD1 requirement review

`DRCU REQ-64`

`The SCU shall implement totally electrically independent main and redundant thermometry channels…`

Fulfilled by design; no redundancy on QM1.

`DRCU REQ-65`

`Temperature probe bias shall be individually switched on/off by a low level command.`

TempOnOff and SubKOnOff (AD7, §6.2) commands were individually tested in both Off and On configurations.

`DRCU REQ-66`

`The SCU shall have two independent photometer/spectrometer calibrator interfaces and associated electronics: 1 for the main configuration + 1 for the redundant configuration (IRD-CALP-R15).`

Fulfilled by design; no redundancy on QM1.

`DRCU REQ-67`

`Calibrator bias current shall be controlled individually by a low-level command.`

PhCalCurSP, Scal2CurSP and SCal4CurSP (AD7, §6.2) DAC programming commands were extensively tested over the full variation range.

`DRCU REQ-68`

`Both voltage and current of the photometer/spectrometer calibrators shall be monitored by the SCU and transmitted to the DPU after digitisation.`

PhCalCur, Scal2Cur, SCal4Cur, PhCalVolt, Scal2Volt and SCal4Volt (AD7, §6.2) current and voltage monitoring commands were extensively tested over the full variation range.

`DRCU REQ-69`

`The SCU is not required to store the calibrator current waveform. Waveforms are generated step by step by the DPU S/W by sending low-level commands regularly (with requirement on the timing accuracy).`

The dynamic properties of the calibrator current response were measured on PhCal (see §3.5.2.6). Scal2 and Scal4 are identical circuit and show similar response times.

DRCU REQ-70

The SCU shall have two independent cryo-cooler and thermal control heaters interfaces and associated electronics: 1 for the main configuration + 1 for the redundant configuration.

Fulfilled by design; no redundancy on QM1.

DRCU REQ-71

Cryo-cooler heaters currents shall be selectable individually with a resolution of 1/4096 w.r.t. the maximum power by independent low-level commands.

Fulfilled by design (12-bit DAC used).

DRCU REQ-72

Thermal control heaters current shall be selectable individually with a resolution of 1/256 w.r.t. the maximum power by an independent low-level command.

Fulfilled by design (12-bit DAC used).

DRCU REQ-73

The SCU shall feature 3 bi-level redundant commands for PSU converter group remote control commands. The signal shall be active high and shall drive a minimum current of 1 mA.

SetParameter command DRelOnOff (AD7, §6.2) verified for all 3 signals, with load currents higher than 1 mA.

DRCU REQ-74

PSU remote commands status shall be configurable by means of SCU low-level commands except for nominal / redundant switching.

GetParameter command DRelOnOff (AD7, §6.2) verified for all 3 signals.

DRCU REQ-75

The SCU shall implement two electrically independent DPU Interface modules (1 main + 1 redundant).

Fulfilled by design; no redundancy on QM1.

DRCU REQ-76

The interface electronics shall transfer fixed size data blocks to the DPU via the fast data interface according to AD11.

Data interface protocol verified.

DRCU REQ-77

The number of blocks to be transferred successively shall be selectable by means of a DCU low-level command. The number of packets to be transferred successively shall be continuous or selectable between 1 and 16.

Command SeqLength (AD7, §6.2) verified (see §8.3). Design allows up to 31 frames per sequence.

DRCU REQ-78

The sampling rate of these data blocks shall be programmable by means of a low-level command between 0.3125 Hz and 80 Hz in 256 steps.

Command FrameConf (AD7, §6.2) verified (see §8.3.1 and 8.3.2).

DRCU REQ-79

The interface module shall transfer the following data (24 words) within a single data format:

Parameter Name	Word size (bits)	Comments
T_PL0	16	Photometer detector box temperature
T_SL0	"	Spectrometer detector box temperature
T_SOB	"	SPIRE Optical Bench temperature
T_SUB	"	Optical sub-bench temperature
T_BAF	"	FPU input baffle temperature
T_FTSM	"	SMEC mechanism temperature
T_FTSS	"	SMEC/SOB I/F temperature
T_SCL4	"	Spectrometer calibrator 4% temperature
T_SCL2	"	Spectrometer calibrator 2% temperature
T_SCST	"	Spectrometer calibrator flange temperature
T_CEV	"	Cryo-cooler evaporator temperature
T_CPHP	"	Cryo-cooler sorption pump temperature
T_CEHS	"	Cryo-cooler evaporator heat switch temperature
T_CPHS	"	Cryo-cooler sorption pump heat switch temperature
T_CSHT	"	Cryo-cooler thermal shunt temperature
T_BSMM	"	BSM mechanism temperature
T_BSMS	"	BSM/SOB I/F temperature
PhCalBias	"	Bias current of photometer calibrator
PhCalVolt	"	Voltage across photometer calibrator
SCal4Bias	"	Bias current of spectrometer calibrator (4%)
SCal4Volt	"	Voltage across spectrometer calibrator (4%)
SCal2Bias	"	Bias current of spectrometer calibrator (2%)
SCal2Volt	"	Voltage across spectrometer calibrator (2%)
TCHeaterBias	"	TC heater bias current

The actual frame format and order produced by QM1 are given in the following (see 8.3):

	Parameter Name	Word size (bits)	Comments
#1	T_CPHP	16	Cryo-cooler sorption pump temperature
	T_CPHS	“	Cryo-cooler sorption pump heat switch temperature
	T_CEHS	“	Cryo-cooler evaporator heat switch temperature
	T_CSHT	“	Cryo-cooler thermal shunt temperature
#5	T_SOB	“	SPIRE Optical Bench temperature
	T_SL0	“	Spectrometer detector box temperature
	T_PL0	“	Photometer detector box temperature
	T_SUB	“	Optical sub-bench temperature
	T_BAF	“	FPU input baffle temperature
#10	T_BSMS	“	BSM/SOB I/F temperature
	T_SCL2	“	Spectrometer calibrator 2% temperature
	T_SCL4	“	Spectrometer calibrator 4% temperature
	T_SCST	“	Spectrometer calibrator flange temperature
	T_FTSS	“	SMEC/SOB I/F temperature
#15	T_FTSM	“	SMEC mechanism temperature
	T_BSMM	“	BSM mechanism temperature
	T_CEV	“	Cryo-cooler evaporator temperature
#18	TCHeaterVolt	“	TC heater bias voltage
#19	PhCalBias	“	Bias current of photometer calibrator
	PhCalVolt	“	Voltage across photometer calibrator
	SCal4Bias	“	Bias current of spectrometer calibrator (4%)
	SCal4Volt	“	Voltage across spectrometer calibrator (4%)
#23	SCal2Bias	“	Bias current of spectrometer calibrator (2%)
#24	SCal2Volt	“	Voltage across spectrometer calibrator (2%)

Note that parameter #18 is is a measurement of the TC Heater voltage, not the current. Its name is changed to TcHeaterVolt.

DRCU REQ-80

The SCU shall include temperature measurement of each of its printed circuit board (except back plane) at location where hot spot or high power dissipation parts (i.e. DC/DC converter switching transistors) are identified.

DRCU REQ-81

Temperature measurement shall be done using an AD590 probe in F02 package glued on the printed circuit board.

DRCU REQ-82

The temperature measurement shall be compliant with the following table:

Temperature Range	-40°C to 88 °C
Temperature resolution	0.5°C

Parameters CsuTempRd and TsuTempRd were verified. The corresponding AD590 probes were checked for functionality (see §3.5.2.6.2). Resolution and range verified (see §6.1). Precision and accuracy taken from data sheet (not verified).

DRCU REQ-83

The SCU shall report the following housekeeping parameters when requested by low-level commands:

Parameter Name	Word size (bits)	Comments
T_PL0	16	Photometer detector box temperature
T_SL0	"	Spectrometer detector box temperature
T_SOB	"	SPIRE Optical Bench temperature
T_SUB	"	Optical sub-bench temperature
T_BAF	"	FPU input baffle temperature
T_FTSM	"	SMEC mechanism temperature
T_FTSS	"	SMEC/SOB I/F temperature
T_SCL4	"	Spectrometer calibrator 4% temperature
T_SCL2	"	Spectrometer calibrator 2% temperature
T_SCST	"	Spectrometer calibrator flange temperature
T_CEV	"	Cryo-cooler evaporator temperature
T_CPHP	"	Cryo-cooler sorption pump temperature
T_CEHS	"	Cryo-cooler evaporator heat switch temperature
T_CPHS	"	Cryo-cooler sorption pump heat switch temperature
T_CSHT	"	Cryo-cooler thermal shunt temperature
T_BSMM	"	BSM mechanism temperature
T_BSMS	"	BSM/SOB I/F temperature
PhCalBias	"	Bias current of photometer calibrator
PhCalVolt	"	Voltage across photometer calibrator
SCal4Bias	"	Bias current of spectrometer calibrator (4%)
SCal4Volt	"	Voltage across spectrometer calibrator (4%)
SCal2Bias	"	Bias current of spectrometer calibrator (2%)
SCal2Volt	"	Voltage across spectrometer calibrator (2%)
TCHeaterBias	"	TC heater bias current
TsuTempRd	"	Temperature module temperature
CsuTempRd	"	Cal/Cool/HK module temperature
PsuTempRd	"	PSU internal temp.
ScuCHTp05	"	SCU +5V power supply voltage
ScuCHTp09	"	SCU +9V power supply voltage
ScuCHTn09	"	SCU -9V power supply voltage
DRelOnOff	3	Status of PSU remote command
ScuStatus	2	Status of SCU electronics

SCU is not compliant on the following items:

- Parameter TcHeaterBias is a measurement of the TC Heater voltage, not the current. Its name is changed to TcHeaterVolt.
- Additional heater voltage parameters: SPHeaterVolt, SPHSHeaterVolt, EVHSHeaterVolt.
- Additional DC level monitoring parameters: ScuCHTP25, ScuCHTRef, ScuCHTgnd, ScuTHTRef, ScuTHTgnd (see AD7, §6.2); verification: see §6.2.

All other parameters implemented and verified.

DRCU REQ-84

The analogue channels (for sub-systems supply voltage reporting) shall have the following characteristics

Voltage channels number	3
Voltage range	≥ nominal voltage + 20 %
Voltage resolution	1 %

Circuit dividers and ADC conversion range were selected to fulfil requirement. See verification in §6.2.

DRCU REQ-85

The thermometry sub-system (main part) shall have the following channels…

Acronym	Location	Sensor Type	Temperature Range	Resolution	Accuracy
T_PL0	Photometer detector box temperature	CX-1030	1 K -10 K	2 mK	2 mK
T_SL0	Spectrometer detector box temperature	CX-1030	1 K -10 K	2 mK	2 mK
T_SOB	SPIRE Optical Bench temperature	CX-1030	3 K - 300 K	10 mK	10 mK
T_SUB	Optical sub-bench temperature	CX-1030	3 K-100 K	25 mK	25 mK
T_BAF	FPU input baffle temperature	CX-1030	3 K-100 K	10 mK	10 mK
T_FTSM	SMEC mechanism temperature	CX-1030	3 K - 20 K	10 mK	10 mK
T_FTSS	SMEC/SOB I/F temperature	CX-1030	3 K - 100 K	25 mK	50 mK
T_SCL4	Spectrometer calibrator 4% temperature	CX-1030	4 K - 150 K	5 mK	5 mK
T_SCL2	Spectrometer calibrator 2% temperature	CX-1030	4 K - 150 K	5 mK	5 mK
T_SCST	Spectrometer calibrator flange temperature	CX-1030	1K - 50 K	10 mK	10 mK
T_CEV	Cryo-cooler evaporator temperature	CX-1030	0.25 K - 10 K	0.1 mK	5 mK
T_CPHP	Cryo-cooler sorption pump temperature	CX-1030	1.5 K - 50 K	0.5 K	1 K
T_CEHS	Cryo-cooler evaporator heat switch temperature	CX-1030	1.5 K - 25 K	0.5 K	1 K
T_CPHS	Cryo-cooler sorption pump heat switch temperature	CX-1030	1.5 K - 25 K	0.5 K	1 K
T_CSHT	Cryo-cooler thermal shunt temperature	CX-1030	1.5 K 10 K	0.1 K	0.1 K
T_BSMM	BSM mechanism temperature	CX-1030	3 K - 20 K	10 mK	10 mK
T_BSMS	BSM/SOB I/F temperature	CX-1030	3K - 80 K	5 mK	5 mK

Note : Resolution is applicable to the lower end of the nominal temperature range.

Channel gains and ADC conversion range were selected to fulfil the resolution requirement. For most channels, the accuracy requirement (expressed in temperature units) over the full range could not be reached with a simple linear channel characterisation. A study was conducted to find the (low temperature side) linear acceptance sub-range. No detailed temperature variation survey was made on the QM1. See results and discussion in §4.3.

DRCU REQ-86

The thermometry sub-system (redundant part) shall have the following channels…

No redundancy on QM1.

DRCU REQ-87

In order to avoid probe self-heating the biases shall not exceed the values given by the following table:

Probe Type	Max. bias
Sub-K probes	40 nA
Standard probes	10 mV

Temp probe bias current and voltage not directly measured nor screened. Constant bias values indirectly reflected in channel gain measurements. Due to component dispersion, voltage levels were observed slightly higher than 10 mV on some FpuTemp channels.

DRCU REQ-88

The SCU shall provide PCAL bias current according to the following performances:

Heater Bias Current Range	0 to 7 mA	in 4096 steps	AD22-7.2.1 &AD22-7.2.2
Maximum dissipated power limitation	10 mW		AD22-7.2.1
Heater Resistance Range	200 to 500 Ω	•100 Ω for lead resistance	AD22-7.2
Stability / Repeatability	0.5 % or 5 µA	Whichever is greater	AD22-7.2.5
Maximum drive voltage	3.9 V	Worst case	AD22-7.2.3
Bias waveform	square		Spec. for DPU
Waveform frequency	0 to 5 Hz		Spec. for DPU
Waveform resolution	100 ms		Spec. for DPU
Interface Type	2x2-wire		None connected to ground

See results in §3.5.2.

DRCU REQ-89

The SCU shall provide SCAL (4% and 2%) biases according to the following performances:

Heater Bias Current Range	0 to 5.5 mA	in 4096 steps	AD23-6.3
Maximum dissipated power limitation	15 mW		AD23-6.2
Heater Resistance Range	500 Ω	•100 Ω for lead resistance	AD23-6.1
Stability / Repeatability	0.5 % or 5 µA	Whichever is greater	AD23-6.5
Maximum drive voltage	3.1 V	Worst case	AD23-6.4
Bias waveform		DC	
Electrical Interface Type	2x2-wire		None connected to ground

See results in §3.6.2 and 3.6.3.

DRCU REQ-90

The above stability and repeatability shall be achieved for operating time of 1 hour (typical observation duration) and assuming a S/C temperature drift of 3K/hour.

A limited survey was conducted on the PhCal channel (§3.5.2.6.2).

DRCU REQ-91

The calibrator current shall be limited by hardware to 110 ± 2 % of specified maximum.

Guaranteed by design. Full range variation summarised in §7.1.5.

DRCU REQ-92

The SCU shall provide cryo-cooler heater biases according to the following performances:

Type	Number	Heater Resistance	Lead Resistance	Power	Absolute max. voltage	Interface type
Heat Switch [1]	2	402 Ω	≤100 Ω	0 / 1 mW	15 V	2x2-wire
Sorption Pump[1]	1	402 Ω	≤100 Ω	0 to 500 mW	15 V	2x2-wire
TC heater	1	6 kΩ	≤ 1kΩ	300 mV / 50 µA		

See results in §3.2.2, 3.3.2, 3.3.3 and 3.4.2.

SPHeater is assumed to have 40 Ω maximum harness resistance, or 0.5 W spec. may not be reached. No special circuit installed to limit voltage to exactly 15V on SPHeater. SPHeater saturation occurs at ~15.6V.

DRCU REQ-93

Both data and command interfaces shall be compliant with AD11.

Signal protocol checked. Set/GetParameter exchange checked directly by digital response analysis, or indirectly by analogue response analysis. Frame format and protocol verified on a bit-per-bit basis for all variants.

DRCU REQ-94

The SCU electronics shall be implemented into 5 DRCU boards (220 x 237 mm PCB) as described §3.1.2. Total allocated volume is then 237 x 220 x 137.5 (dimensions in millimetres).

By design.

DRCU REQ-95

The geometry of the back plane of the SCU shall be compliant with the dimensions given by the figure 4.4-b.

By design.

DRCU REQ-96

The SCU electronics shall operate with the following set of supplies with associated maximum average current:

Supply name	Supply voltage	min. current	max. current
SCU_ANA_P9 SCU_ANA_N9	+9.0 -0.1/+0.1 V -9.0 -0.1/+0.1 V	0.11 A 0.08 A	0.32 A 0.28 A
SCU_DIG_P5	+ 5.20 -0.05/+0.05V	0.13 A	0.22 A
Allocated average power		4.7 W	

Range: Functionality was verified in the required range. However, detailed analogue performance analysis was only conducted at the +9V,-9V and +5V operating point.

Consumption: Measured during integration phases.

DRCU REQ-97

When powered inrush current shall be limited by the SCU according to the following limits:

TBD - from PSU specification document.

Taken into account in design. No special verification.

DRCU REQ-98

The SCU shall provide proper supply line filtering to restrict the conducted emissivity as specified below:

TBD - from PSU specification document.

Taken into account in design. No special verification.