Note on temperature readout of SCT modules

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Measurement of module temperature

The temperature on the barrel and forward silicon strip detector modules in SCT will be sensed by thermistors mounted on the hybrid. The barrel modules have two thermistors and the forward modules have only one thermistor, because of the double sided design. The signals from the thermistors are brought to the power supplies in the control room by the same route as the power is brought to the modules. The biasing and readout of the temperature sensors on the modules are integrated in the power supplies. Figure 1. shows a schematic drawing of the temperature readout.

The thermistor shares the sense wire for Digital Ground which reduces the total number of wires to be routed to the modules. The differential signal from the thermistor is digitized by a 10 bit ADC and sent to the crate controller in the power supplies.

Readout with thermistors

Negative Thermal Coefficient, NTC, thermistors are favored for temperature monitoring on detector modules before platinum resistors mainly because of the small size. The thermistors have a large change in resistance with temperature but the response is nonlinear. The relation between resistance and temperature for a thermistor is given by

$$R = R_{ref} e^{\left(\frac{B}{t} - \frac{B}{t_{ref}}\right)}$$

where R_{ref} is the resistance of the thermistors at temperature t_{ref}, typically 25 °C . The parameter B is the temperature coefficient, typically between 2000K and 5000 K. Inverting the formula gives the relation between temperture and resistance.

$$t = \frac{B}{\left(\ln\left(\frac{R}{R_{ref}}\right) + \frac{B}{t_{ref}}\right)}$$

A response curve for a 10kOhm thermistor is shown in figure 2.

The thermistors can be found in various sizes and accuracy. The smallest size found in a fast market survey has the size SMD 0603 (L1.6mm × W0.8 mm × T0.9 mm) with an accuracy of R_{ref} ±5 % and $B \pm 3\%$. Individual calibration of single thermistors is not desirable in SCT hence the inaccuracy of the thermistor will be reflected as a spread in temperature between modules. Temperature spread as a function of thermistor resistance is shown in figure 3a. Note the logarithmic scale on x–axis. Profile histograms of temperature spread at thermistor resistances 3.5 kΩ, 15 kΩ and 100 kΩ are shown in figures 3b–d.

Response curves for a large number of thermistors with the above accuracy as a function of ADC counts in a 10 bit ADC is shown in figure 4a. Note that the x–axis is now linear because of a linear ADC. Figures 4b–d show histograms of spread in ADC counts at temperatures 50 °C, 20 °C and −20 °C.

The performance of a readout system with a 10 bit ADC and thermistors can be deduced from the two sets of plots in figures 3 and 4 by comparing temperature spread and ADC spread. The resolution of the above described thermistor based system is listed in table I.

Temperature [°C]	**Temperature spread RMS [°C]**	**ADC spread RMS [counts]**	**ADC resolution [°C/counts]**
50	1,5580	0,7281	2,1398
20	1,0890	0,5840	1,8647
−20	1,4300	62,4700	0,0229

Table I. Performance of a thermistor based system.

The specification for temperature measurement in "The Semiconductor Tracker Detector Control System Requirements Document"* is 0.3 °C relative precision and 1 °C absolute precision. With a 5%/3% thermistor the specification on absolute precision, column 2, is not met. Because of the exponential behavior of the thermistor the specification on relative precision can not be met even in a range −20 °C to 20 °C . At 20 °C the performance has to be improved by a factor of 7. The specification on absolute precision over a range −20 °C to 50 °C can be met by using 2%/2% precision thermistors, figure 4a–d.

An improved relative precision can be achieved with several methods. If the 10–bit ADC is kept the simplest method is to have a bias current which can be adjusted depending on which temperature range is needed. A method to improve the bandwidth is shown in appendix A. The resolution can also be improved by replacing the 10–bit ADC with a 14–bit ADC.

Readout with platinum sensors

For completeness the performance of a platinum thermal sensor based system will be compared. The linear behavior of the platinum sensors allows a more effective use of the ADC bandwidth.

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* The Semiconductor Tracker Detector Control System Requirements Document, November 15, 1998, EDMS:ATL–IS–ES–0011.

The platinum sensors do not come in as small SMD packages as thermistors which may have implications on the hybrid design. The smallest SMD size found for platinum sensors is SMD 1206 (L3.2mm × W1.6 mm × T0.6 mm). The relation between temperature and resistance of a platinum sensor is given in its most simple form by

$$R_t = R_0(1 + At)$$

where R_0 is the nominal resistance at 0°C and A is a constant for the temperature dependent change in resistance which is $3.908 \cdot 10^{-3}$ / °C for platinum. The most frequently used platinum sensor has 100 Ω nominal resistance. In applications where the distance between the sensor and the readout electronics is big four wire readout has to be used to compensate for the resistance in the wiring. Today platinum sensors with 1000 Ω nominal resistance can be found at the same prices as 100 Ω sensors. The higher value sensors allow two wire readout at medium distances. The performance of a platinum sensor based system is shown in figure 5a–d.

Over a range of 70 °C the ADC resolution for a platinum sensor based system with a 10 bit ADC is 0.07 °C/count. If the range is extended to 100 °C to give some headroom in both ends the resolution is still sufficient, 0.1 °C/count. The nominal resistance of a platinum sensor is lower than of thermistors and the resistance of the wiring may induce additional noise.

Measurement on noise in SCT setup

A study of the effect of wiring on the noise has been studied in a laboratory setup. The cabling that will be in SCT was simulated with an 80 m long conventional copper cable in room temperature and two sections, 300 µm aluminum and 150 µm aluminum, of low mass tapes in an environment chamber. The temperature of a 1000 Ω class B platinum sensor with 2–wire readout through the long cables was compared with a calibrated 100 Ω class A sensor directly read out with four short wires. Data was taken at two different temperatures 20 °C apart. The difference in temperature recorded with the two sensors is shown in figure 6.

The offset of around 7 °C is due to the resistance in the cable that can be corrected for. The two peak structure is due to the difference in cable resistance at two temperatures and cannot be easily corrected for in the experiment, the effect is however small. With a higher nominal resistance in the sensor this effect will be smaller, i.e. at 10 kΩ the effect from the cable will be 10 times smaller.

Conclusions

Monitoring of module temperature with thermistors is possible if the thermistor precision is better than 2%. The logarithmic response of the thermistor has to be compensated for by replacing the 10–bit ADC with a 14–bit ADC or with a tunable excitation current for the thermistor. The effect of cable resistance at low temperatures/low resistance can be reduced by choosing a 50 kΩ thermistor. If a platinum sensor can be fitted on the hybrid this solution can be beneficial because of the linear behavior of the sensor.

Figure captions:

Figure 1. A schematic drawing of the monitoring circuit for module temperature.

Figure 2. Response curve of a 10 kΩ thermistor.

Figure 3a–d.Temperature spread as a function of resistance.

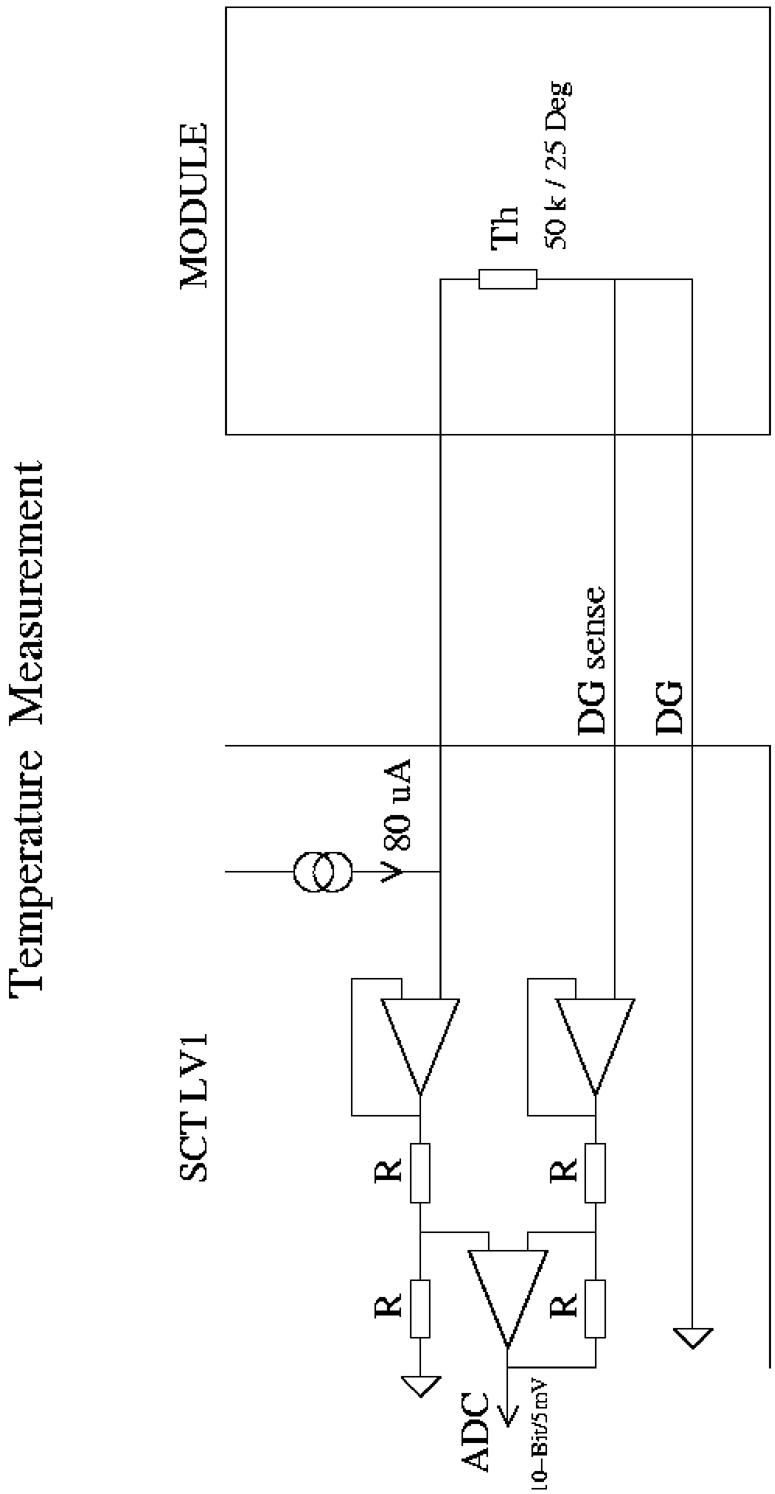
Figure 4a–d. ADC spread as a function of temperature.

Figure 5. Performance of a 2%/2% thermistor system.

Figure 6. Response curve for platinum sensors.

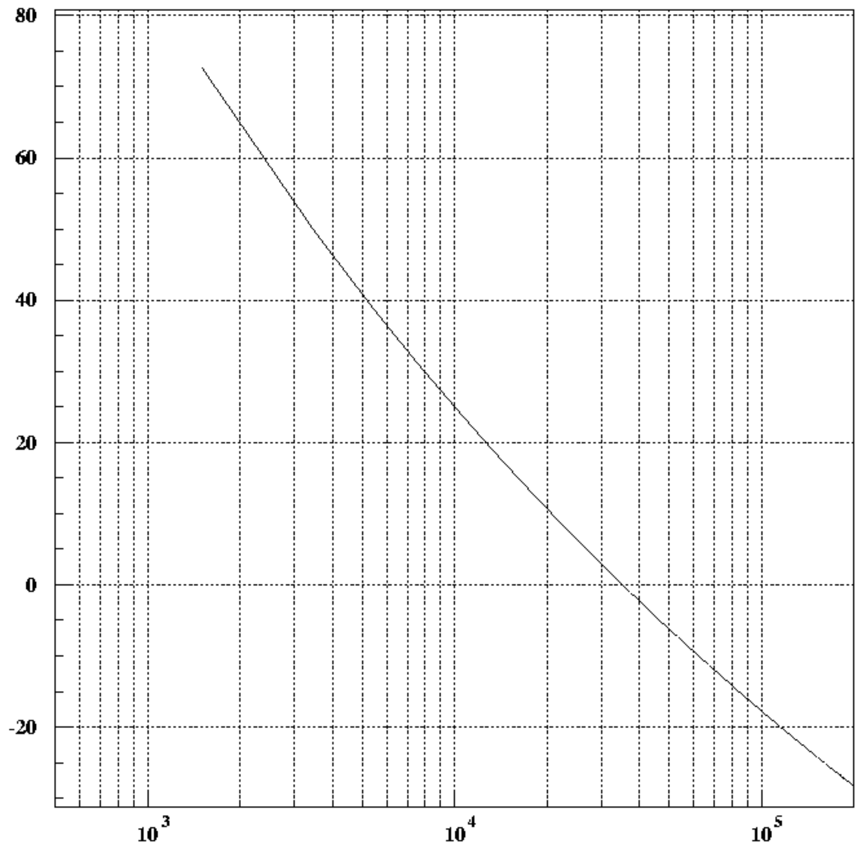
Figure 7. Temperature distribution of platinum sensor in SCT setup.

Figure 1



Temperature Measurement
MODULE
Th
50 k / 25 Deg
DG sense
DG
80 uA
SCT LV1
R
R
R
R
ADC
10-Bit/5mV

Figure 2



10kOhm thermistor t vs. R

Figure 3a−d

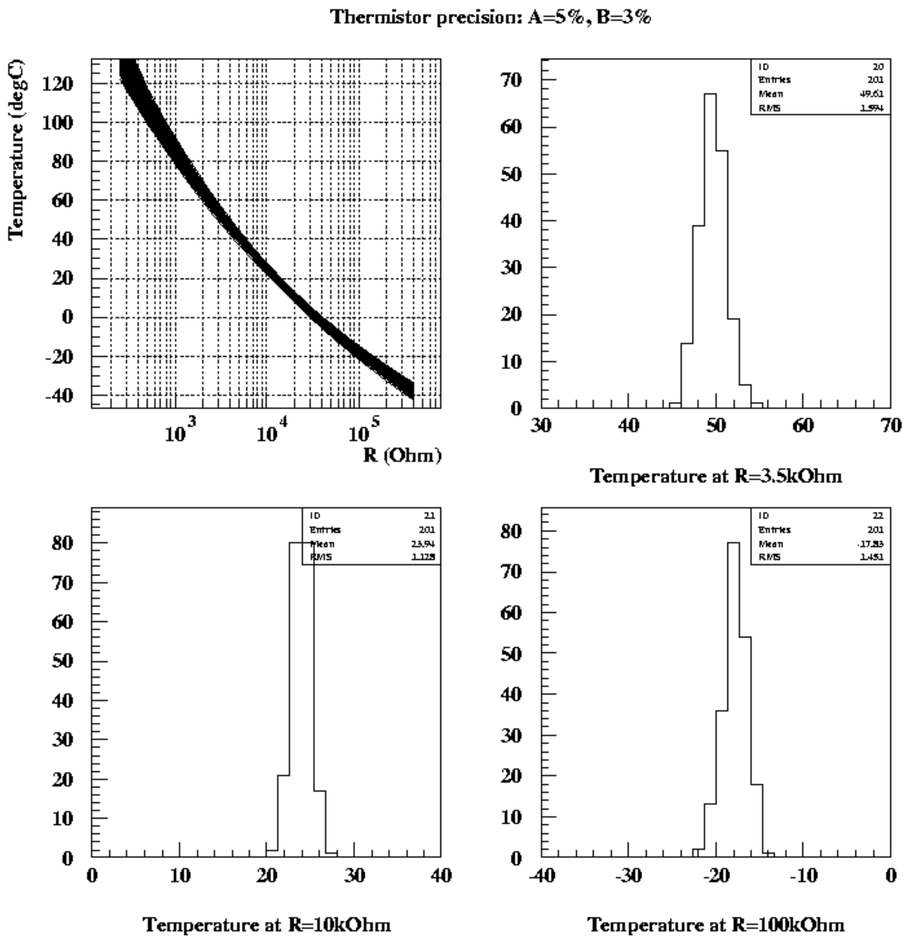

Thermistor precision: A=5%, B=3%
Temperature (degC)
R (Ohm)
Temperature at R=3.5kOhm
Temperature at R=10kOhm
Temperature at R=100kOhm

Figure 4a−d

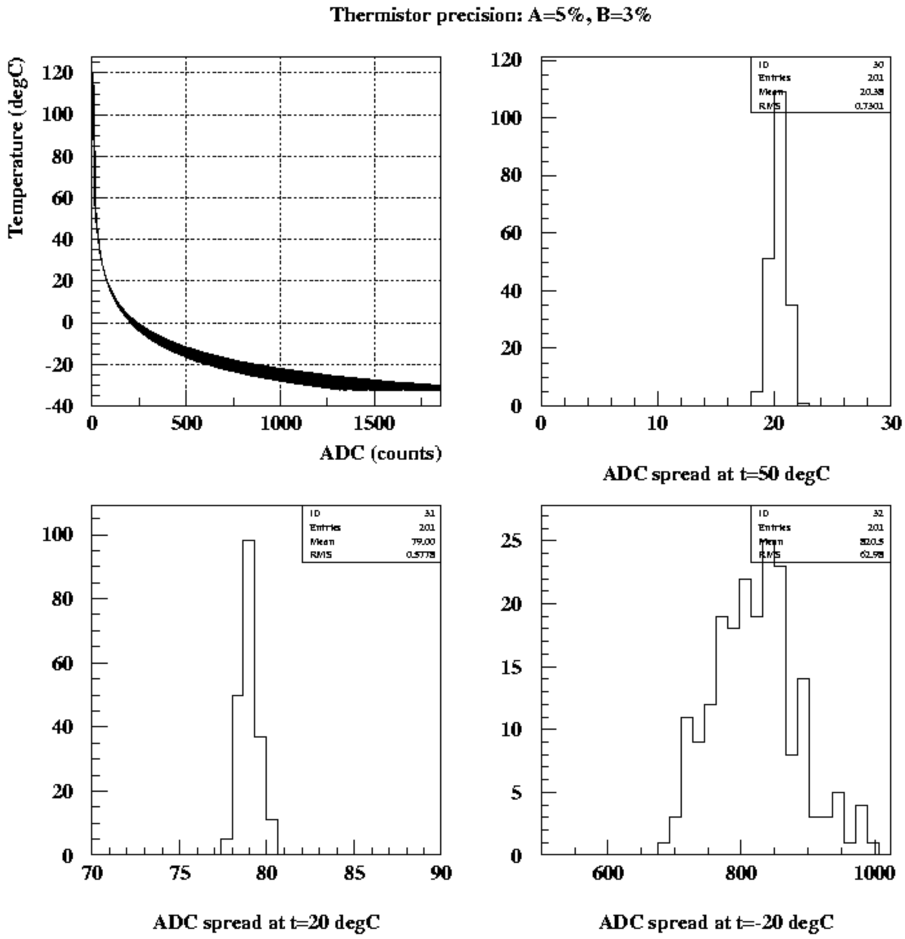
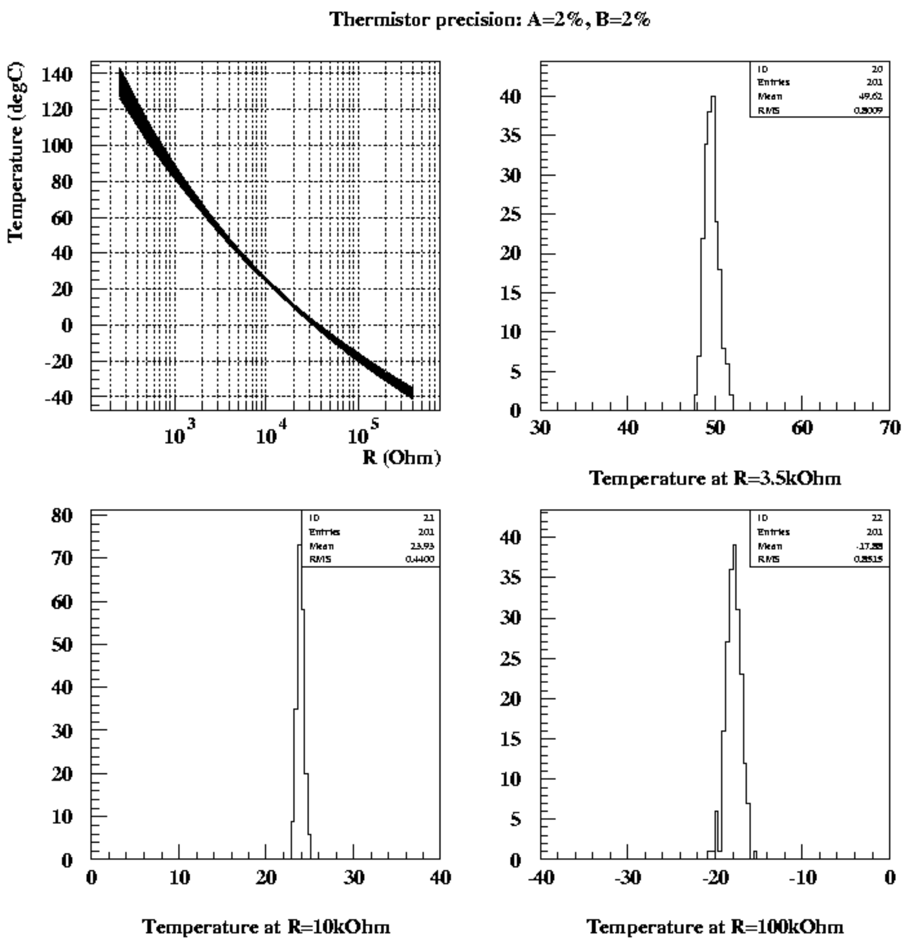
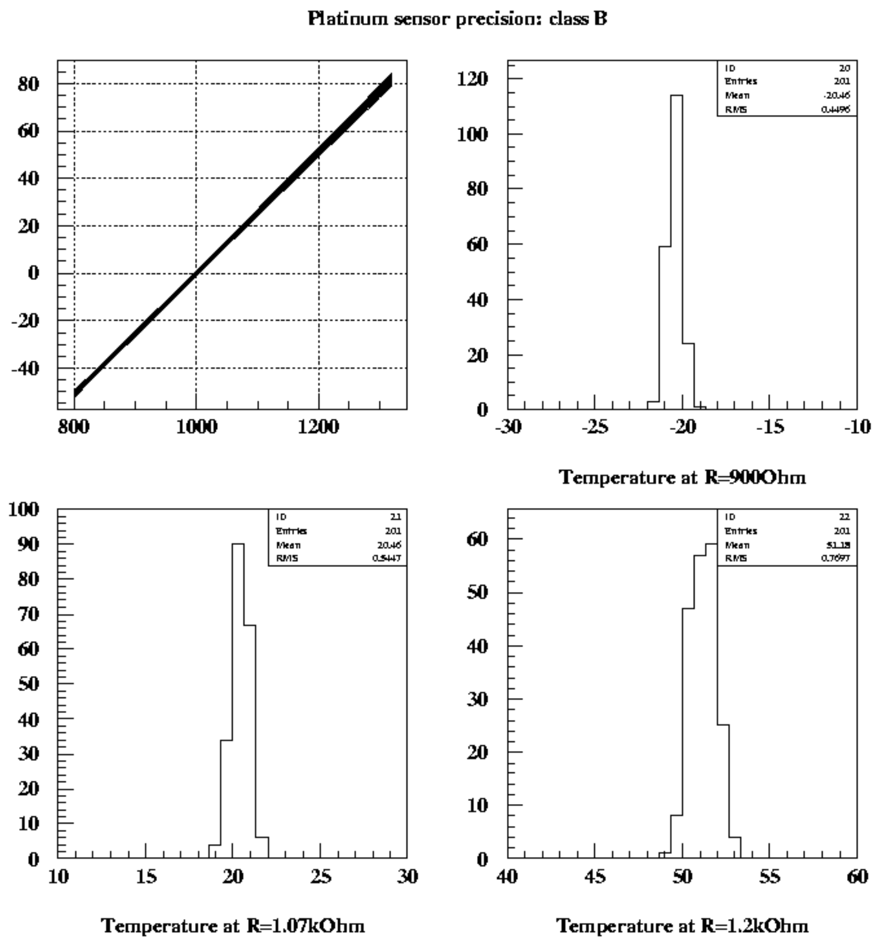

Thermistor precision: A=5%, B=3%
Temperature (degC)
ADC (counts)
ID 30
Entries 201
Mean 20.38
RMS 0.7301
ADC spread at t=50 degC
ID 31
Entries 201
Mean 79.00
RMS 0.5778
ADC spread at t=20 degC
ID 32
Entries 201
Mean 820.5
RMS 62.98
ADC spread at t=-20 degC

Figure 5a–d



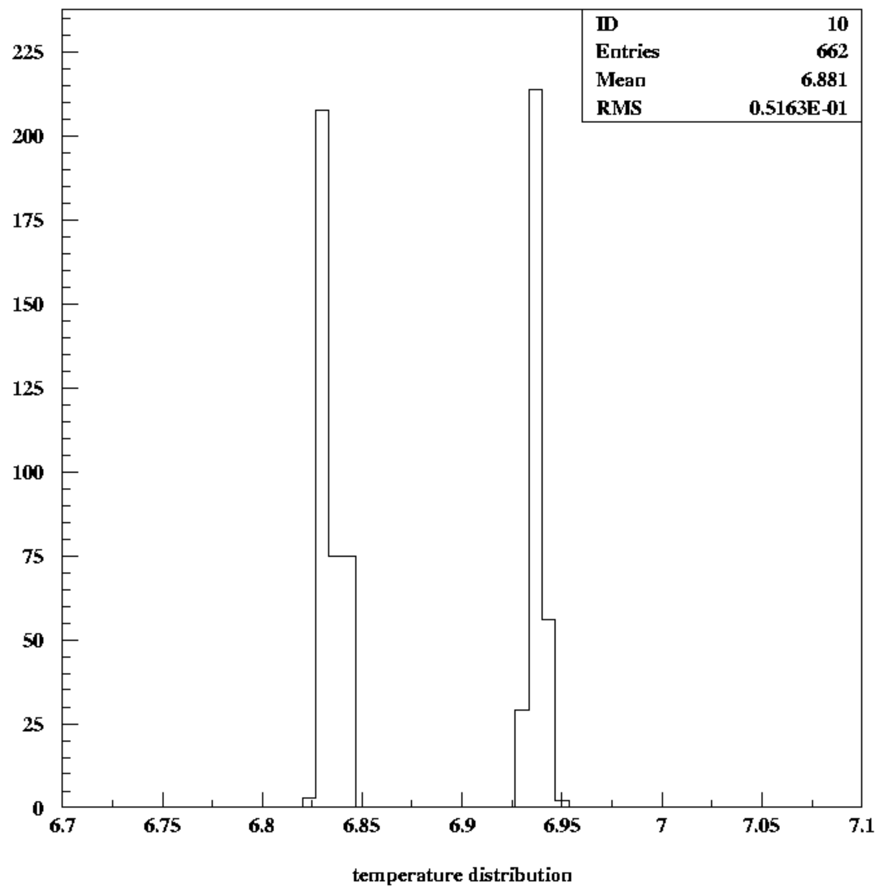
Thermistor precision: A=2%, B=2%
Temperature (degC)
140
120
100
80
60
40
20
0
-20
-40
10^3
10^4
10^5
R (Ohm)
ID 20
Entries 201
Mean 49.62
RMS
30
40
50
60
70
Temperature at R=3.5kOhm
ID 21
Entries 201
Mean 23.93
RMS 0.4400
0
10
20
30
40
Temperature at R=10kOhm
ID 22
Entries 201
Mean
RMS
-40
-30
-20
-10
0
Temperature at R=100kOhm

Figure 6a−d



Platinum sensor precision: class B
80
60
40
20
0
-20
-40
800
1000
1200
ID 20
Entries 201
Mean -20.46
RMS 0.4496
120
100
80
60
40
20
0
-30
-25
-20
-15
-10
Temperature at R=900Ohm
ID 21
Entries 201
Mean 20.46
RMS 0.5447
100
90
80
70
60
50
40
30
20
10
0
10
15
20
25
30
Temperature at R=1.07kOhm
ID 22
Entries 201
Mean 51.18
RMS 0.7697
60
50
40
30
20
10
0
40
45
50
55
60
Temperature at R=1.2kOhm

Figure 7



ID 10
Entries 662
Mean 6.881
RMS 0.5163E-01
0
25
50
75
100
125
150
175
200
225
6.7
6.75
6.8
6.85
6.9
6.95
7
7.05
7.1
temperature distribution

Appendix A

Contribution from Nils Bingefors, Uppsala University, Sweden

A schematic drawing of circuit for connecting a thermistor which will improve the use of ADC bandwidth.