ATLAS project	**Temperature readout errors in thermistors due to voltage ambiguities**		
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Project breakdown name

Temperature readout errors in thermistors due to voltage ambiguities

abstract

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Distribution List

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History of Changes

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Table of Contents

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5. From the menu, click “File” > “Generate”
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7. If there exits the associated xxx.TOC file, it will be updated. If not, a xxx.TOC file will be created
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1 Introduction

In the ATLAS SCT modules, temperatures of the hybrid in a module will be monitored with thermistors. Thermistors have larger resistances, e.g., 10 kΩ, than those of platinum resistors, such as PT100 (100Ω) or PT1000 (1kΩ), thus larger sensitivity to temperature to the limitation of the accuracy of readout devices. The resistance of the readout wires introduces an error, but as long as the current through the wires is known, the error can be calibrated out. In the hybrid, when the common ground is used for the return of the thermistor and the return of the ASIC chips, there could be voltage error due to the resistance of the ground and the current of the chips, and thus the error in temperature. Although the voltage error due to the ASIC current can be calibrated by monitoring the current, it is not straightforward to correct the temperature instantaneously. The operation temperature of interest of the module is at room and around -20 °C temperature.

2 Resistivity of thermistors

Thermistors have a well defined temperature dependence,

$$R = R_0 \exp\left(B\left(\frac{1}{T} - \frac{1}{T_0}\right)\right) \quad (1)$$

The sensitivity to temperature is then

$$(\Delta R)/(\Delta T) = -(B/T^2) \cdot R \ . \quad (2)$$

For a typical thermistor with the parameters of R0=10 kΩ at 25 °C and B = 3435 K, the resistance R varies from 248 kΩ at -40 °C to 1.7 kΩ at 80 °C, and the sensitivity from -16 kΩ/K to -0.05 kΩ/K, respectively, and -0.5 kΩ/K at 20 °C. Specific calculations are given in Section 3.

2.1 Contribution from the Ro and B parameters

The resistance has ambiguity contribution from the Ro and B parameters as

$$\delta R = ((\delta R_o)/R_o)R \quad (3)$$

and

$$\delta R = ((\delta B)/B)B(1/T - 1/T_0)R \ . \quad (4)$$

Typically, the tolerances are $(\delta R_0)/R_0 = 0.01$ and $(\delta B)/B = 0.01$. For the above example, the temperature ambiguity due to the ambiguity of Ro is 0.2 to 0.4 K at -40 and +80 °C, respectively, while that due to the ambiguity of B varies from 0 K at 25 °C to 0.5 K at -40 °C and 0.7 K at 80 °C. This means when two thermistors are selected, there could be 0.5 K ambiguity in temperature typically. The estimation of the ambiguities as a function of temperature is given in the table “Ro and B errors”.

3 Voltage sensitivity to temperature

In order to readout the resistance, there are several modes of operation: constant voltage, constant power, and constant current. The sensitivity of the voltage to temperature is evaluated for each mode. One caution to be kept in mind is the power rating of the thermistors which may require a special attention to change the voltage or current when the power exceeds the rating. A surface mount thermistor, e.g., is rated to be 4.5 mW at 25 °C.

3.1 Constant voltage operation

An example calculations are given in the tables “ConstV” for the constant voltage of 1.5 V and “ConstV (2)” of 3.0 V. At 1.5 V, the voltage sensitivity varies; 95, 60, and 41 mV/K at -40, +20, and +80 °C, respectively. The power in the thermistor varies; <0.1, 0.2, and 0.4 mW, respectively. At 3.0 V, the sensitivity increases twice: 190, 120, and 83 mV/K, while the power varies: <0.1, 0.7, and 5.4 mW, which is slightly over power, respectively.

3.2 Constant power operation

Since the power dissipation varies a lot, a mode of operation of constant power could be envisaged. An example of power at 3 mW is given in the table “ConstW”. For this mode of operation, the voltage sensitivity varies;1725, 242, and 62 mV/K, respectively. The voltage and current varies; 27 V and 0.11 mA, 6 V and 0.5 mA, and 2.2 V and 1.3 mA, respectively.

3.3 Constant current operation

The case the thermistor is operated under the constant current of 0.1 mA is given in the table “ConstI”. The voltage sensitivity varies; 1570, 49, and 4.6 mV/K, respectively. The sensitivity and the variation indicate that the constant current is not an appropriate mode of operation of thermistor.

4 Resistances of ground layers and voltage ambiguities due to ASIC currents

The resistance of the ground layers are summarized in the table “Temp errors”. The resistances from the module connector, including the contact resistance of connector pins, to the thermistors, Temp1 and Temp2, are derived from the measurement of resistances for the barrel Cu/Polyimide hybrid version 3 with the ground layer thickness of 12 µm. Three cases are listed: DGND, AGND, and A+DGND, where the digital, and the analog, and the sum of the digital and the analog ground layers are considered. The ASIC currents, digital and analog, are taken to vary 0.5 A in each for the maximum variation. The analog current varies very little for a setting of frontend bias and shaper current. The variation of 0.5 A for the analog is taken for the case that the frontend bias and shaper currents are varied. The digital current varies depending on the fraction of hit-no hit. The maximum current is observed when the fraction is 50-50%. The digital current is smaller for any other fractions.

The largest resistance is the one to the Temp2 with DGND used: 46 mΩ, being 19 mΩ when the AGND and DGND are combined. With the variation of the currents, the voltage ambiguity could be 23 mV and 19 mV, respectively. If the voltage sensitivity of thermistor is 50 mV/K, the voltage error could introduce a temperature ambiguity of 0.5 and 0.4 K, respectively. From the numbers in Section 3, the constant voltage operation of 1.5 V would give 0.3, 0.4, and 0.6 K ambiguity at -40, +20, +80 °C, respectively. The constant power operation of 3 mW would give 0.02, 0.1, and 0.4 K ambiguities.

The resistance difference of two thermistors is small, 8 mΩ in DGND and 6.3 mΩ when AGND and DGND combined. The temperature ambiguity for a voltage sensitivity of 50 mV/K is 0.2 K and <0.1 K.

Increasing the thickness of the ground layer, e.g., 17 μm from 12 μm, will reduce the temperature ambiguity by 30%, 0.35 K from 0.5 K.

5 Conclusion

Thermistors of 10 kΩ at 25 °C would have about 0.5 K temperature ambiguity due to product tolerances. Common grounding of the return of the thermistors and the ASICs introduces ambiguity of voltage readout of 23 mV in the worst case, which then introduces temperature ambiguity depending on the voltage sensitivity of the thermistors. The voltage sensitivity of thermistors varies depending on the mode of operation. A simple constant voltage operation of 1.5 V would give an ambiguity of <0.4 K in the temperature range of interest of -40 and +20 °C. A constant voltage operation of 3.0 V would halve the ambiguity but has to be reduced less than 3 V for >80°C in order to limit the power dissipation. A constant power operation of 3 mW could give a smaller ambiguity of <0.1 K in the range of interest and <0.4 K up to 80 °C. Increasing the ground layer thickness reduces the temperature ambiguity further.

References

[1] Author(s), “Title”, reference id, date

Thermistor

R = R0•exp(B•(1/T - 1/T0))

ΔR/ΔT=-B/T^2•R ∂R=∂R0/R0•R ∂R=∂B/B•(B(1/T-1/T0)•R

R: resistance at absolute temp. T
R0: resistance at absolute temp. T0
R25: zero-power resistance at 25 °C

Ishizuka	R25	B [K]	Dissipation factor [mW/K]	Thermal time const [s]	Rated power at 25 °C [mW]	Operating temp. range [°C]
10KC15-1608-1P	10 kΩ±1%	3435±1%	0.9	5	4.5	-40 ~ 125

R25 [kΩ]	10			
B [K]	3435			
Constant V [V]	1.5		∂R0/R0=0.01	∂B/B=0.01
T [°C]	R [kΩ]	ΔR/ΔT [kΩ/K]	∂T [K]	∂T [K]
-40	248.277	-15.689	-0.2	-0.5
-30	135.452	-7.870	-0.2	-0.4
-20	77.523	-4.155	-0.2	-0.4
-10	46.290	-2.296	-0.2	-0.3
0	28.704	-1.322	-0.2	-0.2
10	18.410	-0.789	-0.2	-0.1
20	12.171	-0.487	-0.3	0.0
30	8.269	-0.309	-0.3	0.1
40	5.759	-0.202	-0.3	0.2
50	4.101	-0.135	-0.3	0.3
60	2.981	-0.092	-0.3	0.4
70	2.207	-0.064	-0.3	0.5
80	1.662	-0.046	-0.4	0.7
90	1.272	-0.033	-0.4	0.8
100	0.987	-0.024	-0.4	0.9
110	0.776	-0.018	-0.4	1.1
120	0.618	-0.014	-0.4	1.3

Thermistor

R = R0•exp(B•(1/T - 1/T0))
ΔR/ΔT=-B/T^2•R

R: resistance at absolute temp. T
R0: resistance at absolute temp. T0
R25: zero-power resistance at 25 °C

Ishizuka	R25	B [K]	Dissipation factor [mW/K]	Thermal time const [s]	Rated power at 25 °C [mW]	Operating temp. range [°C]
10KC15-1608-1P	10 kΩ±1%	3435±1%	0.9	5	4.5	-40 ~ 125

R25 [kΩ]	10						
B [K]	3435						
Constant V [V]	1.5						after 1s
T [°C]	R [kΩ]	ΔR/ΔT [kΩ/K]	I [mA]	ΔV/ΔT [mV/K]	V [V]	W [mW]	∂T [K]
-40	248.277	-15.689	0.006	-94.8	1.5	0.0	0.0
-30	135.452	-7.870	0.011	-87.2	1.5	0.0	0.0
-20	77.523	-4.155	0.019	-80.4	1.5	0.0	0.0
-10	46.290	-2.296	0.032	-74.4	1.5	0.0	0.0
0	28.704	-1.322	0.052	-69.1	1.5	0.1	0.0
10	18.410	-0.789	0.081	-64.3	1.5	0.1	0.0
20	12.171	-0.487	0.123	-60.0	1.5	0.2	0.0
30	8.269	-0.309	0.181	-56.1	1.5	0.3	0.1
40	5.759	-0.202	0.260	-52.5	1.5	0.4	0.1
50	4.101	-0.135	0.366	-49.3	1.5	0.5	0.1
60	2.981	-0.092	0.503	-46.4	1.5	0.8	0.2
70	2.207	-0.064	0.680	-43.8	1.5	1.0	0.2
80	1.662	-0.046	0.902	-41.3	1.5	1.4	0.3
90	1.272	-0.033	1.179	-39.1	1.5	1.8	0.4
100	0.987	-0.024	1.520	-37.0	1.5	2.3	0.5
110	0.776	-0.018	1.932	-35.1	1.5	2.9	0.6
120	0.618	-0.014	2.427	-33.3	1.5	3.6	0.7

Thermistor

R = R0•exp(B•(1/T - 1/T0))
ΔR/ΔT=-B/T^2•R

R: resistance at absolute temp. T
R0: resistance at absolute temp. T0
R25: zero-power resistance at 25 °C

Ishizuka	R25	B [K]	Dissipation factor [mW/K]	Thermal time const [s]	Rated power at 25 °C [mW]	Operating temp. range [°C]
10KC15-1608-1P	10 kΩ±1%	3435±1%	0.9	5	4.5	-40 ~ 125

R25 [kΩ]	10						
B	3435						
Constant V [V]	3.0						after 1s
T [°C]	R [kΩ]	ΔR/ΔT [kΩ/K]	I [mA]	ΔV/ΔT [mV/K]	V [V]	W [mW]	∂T [K]
-40	248.277	-15.689	0.012	-189.6	3	0.0	0.0
-30	135.452	-7.870	0.022	-174.3	3	0.1	0.0
-20	77.523	-4.155	0.039	-160.8	3	0.1	0.0
-10	46.290	-2.296	0.065	-148.8	3	0.2	0.0
0	28.704	-1.322	0.105	-138.1	3	0.3	0.1
10	18.410	-0.789	0.163	-128.5	3	0.5	0.1
20	12.171	-0.487	0.246	-119.9	3	0.7	0.1
30	8.269	-0.309	0.363	-112.1	3	1.1	0.2
40	5.759	-0.202	0.521	-105.1	3	1.6	0.3
50	4.101	-0.135	0.731	-98.7	3	2.2	0.4
60	2.981	-0.092	1.006	-92.8	3	3.0	0.6
70	2.207	-0.064	1.359	-87.5	3	4.1	0.8
80	1.662	-0.046	1.805	-82.6	3	5.4	1.1
90	1.272	-0.033	2.359	-78.1	3	7.1	1.4
100	0.987	-0.024	3.039	-74.0	3	9.1	1.8
110	0.776	-0.018	3.865	-70.2	3	11.6	2.3
120	0.618	-0.014	4.855	-66.7	3	14.6	2.9

Thermistor

R = R0•exp(B•(1/T - 1/T0))
ΔR/ΔT=-B/T^2•R

R: resistance at absolute temp. T
R0: resistance at absolute temp. T0
R25: zero-power resistance at 25 °C

Ishizuka	R25	B [K]	Dissipation factor [mW/K]	Thermal time const [s]	Rated power at 25 °C [mW]	Operating temp. range [°C]
10KC15-1608-1P	10 kΩ±1%	3435±1%	0.9	5	4.5	-40 ~ 125

R25 [kΩ]	10						
B	3435						
Constant W [mW]	3.0						after 1s
T [°C]	R [kΩ]	ΔR/ΔT [kΩ/K]	I [mA]	ΔV/ΔT [mV/K]	V [V]	W [mW]	∂T [K]
-40	248.277	-15.689	0.110	-1724.6	27.3	3.0	0.6
-30	135.452	-7.870	0.149	-1171.2	20.2	3.0	0.6
-20	77.523	-4.155	0.197	-817.4	15.3	3.0	0.6
-10	46.290	-2.296	0.255	-584.6	11.8	3.0	0.6
0	28.704	-1.322	0.323	-427.2	9.3	3.0	0.6
10	18.410	-0.789	0.404	-318.4	7.4	3.0	0.6
20	12.171	-0.487	0.496	-241.5	6.0	3.0	0.6
30	8.269	-0.309	0.602	-186.2	5.0	3.0	0.6
40	5.759	-0.202	0.722	-145.6	4.2	3.0	0.6
50	4.101	-0.135	0.855	-115.4	3.5	3.0	0.6
60	2.981	-0.092	1.003	-92.6	3.0	3.0	0.6
70	2.207	-0.064	1.166	-75.1	2.6	3.0	0.6
80	1.662	-0.046	1.343	-61.5	2.2	3.0	0.6
90	1.272	-0.033	1.536	-50.9	2.0	3.0	0.6
100	0.987	-0.024	1.743	-42.5	1.7	3.0	0.6
110	0.776	-0.018	1.966	-35.7	1.5	3.0	0.6
120	0.618	-0.014	2.203	-30.3	1.4	3.0	0.6

Thermistor

R = R0•exp(B•(1/T - 1/T0))
ΔR/ΔT=-B/T^2•R

R: resistance at absolute temp. T
R0: resistance at absolute temp. T0
R25: zero-power resistance at 25 °C

Ishizuka	R25	B [K]	Dissipation factor [mW/K]	Thermal time const [s]	Rated power at 25 °C [mW]	Operating temp. range [°C]
10KC15-1608-1P	10 kΩ±1%	3435±1%	0.9	5	4.5	-40 ~ 125

R25 [kΩ]	10						
B	3435						
Constant I [mA]	0.100						after 1s
T [°C]	R [kΩ]	ΔR/ΔT [kΩ/K]	I [mA]	ΔV/ΔT [mV/K]	V [V]	W [mW]	∂T [K]
-40	248.277	-15.689	0.100	-1568.9	24.828	2.5	0.5
-30	135.452	-7.870	0.100	-787.0	13.545	1.4	0.3
-20	77.523	-4.155	0.100	-415.5	7.752	0.8	0.2
-10	46.290	-2.296	0.100	-229.6	4.629	0.5	0.1
0	28.704	-1.322	0.100	-132.2	2.870	0.3	0.1
10	18.410	-0.789	0.100	-78.9	1.841	0.2	0.0
20	12.171	-0.487	0.100	-48.7	1.217	0.1	0.0
30	8.269	-0.309	0.100	-30.9	0.827	0.1	0.0
40	5.759	-0.202	0.100	-20.2	0.576	0.1	0.0
50	4.101	-0.135	0.100	-13.5	0.410	0.0	0.0
60	2.981	-0.092	0.100	-9.2	0.298	0.0	0.0
70	2.207	-0.064	0.100	-6.4	0.221	0.0	0.0
80	1.662	-0.046	0.100	-4.6	0.166	0.0	0.0
90	1.272	-0.033	0.100	-3.3	0.127	0.0	0.0
100	0.987	-0.024	0.100	-2.4	0.099	0.0	0.0
110	0.776	-0.018	0.100	-1.8	0.078	0.0	0.0
120	0.618	-0.014	0.100	-1.4	0.062	0.0	0.0

Thermistor temperature errors

	Temp1			Temp2			ΔTemp		
	DGND	AGND	A+DGND	DGND	AGND	A+DGND	DGND	AGND	A+DGND
Resistance [mΩ]	29.7	21.5	12.5	45.7	32.0	18.8			
ΔI [A]	0.5	0.5	1.0	0.5	0.5	1.0			
ΔV [mV]	14.8	10.8	12.5	22.8	16.0	18.8	8.0	5.3	6.3
ΔV/ΔT [mV/K]									
10	1.5	1.1	1.2	2.3	1.6	1.9	0.8	0.5	0.6
50	0.3	0.2	0.2	0.5	0.3	0.4	0.2	0.1	0.1
100	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1