BetaTHERM Sensors
TEMPERATURE SOLUTIONS

# ESA/ SCC QUALIFICATION REPORT FOR

# NTC THERMISTOR PART TYPES:

# ESA/SCC 4006/013 & 4006/014

## APPENDIX P

## Issues associated with the Measurement of Resistance of Device No. 1K3A351

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**To:** Ian Pimm (Estec)

**From:** Pat Lyons **Date:** 21-May-01

**Re:** Issues with Qualification Report concerning 1K3A351 device **Pages:** 7

**CC:** Jude Neylon, T. O'Brien, J. Howley, J. Wong.

This memo presents a discussion of the issues relating to burn in and life-test results, reported in the Qualification Report from Betatherm dated Jan 2001, for variant 01 of specification ESA/SCC 4006/013, device type 1K3A351.

The particular issue was raised by J. Howley in the statistical analysis of the data in the Qualification Report. The issue is that the mean drift in resistance value at 25 °C, observed after burn-in at 100 °C for 168 hours, was 0.16 % with a standard deviation of 0.06%. The specification for burn-in drift limit is +/- 0.2%. The results raised two concerns associated with burn-in:

1. That the process is not capable of meeting the specification limit in a volume production situation.
2. The results differ significantly from burn-in results reported in the Qualification Report for other components made from similar material type, for example variant 05 of specification ESA/SCC 4006/013, device type 5K3A355. The burn-in results for this variant were mean drift 0.07% and standard deviation 0.06%.

There are also issues with the life-test results. The life-test stress temperature was 100 °C. The magnitude of reported burn-in drift, for device type 1K3A351, was not reflected in the life-test results for this device type. The results for **1000 hours life-test** were not similar to the results for device type 5K3A355. The mean drift value for 1K3A351 device was 0.13%, with Standard Deviation of 0.09%, and mean drift value for 5K3A355 device was 0.26%, with standard deviation of 0.06%.

The results for **2000 hours life-test** were similar for both devices, mean drift value for 1K3A351 device was 0.47%, with Standard Deviation of 0.13%, and mean drift value for 5K3A355 device was 0.49%, with standard deviation of 0.09%. The concerns associated with the life-test results are:

1. That there is significant difference in the aging mechanisms for 1K3A351 devices and 5K3A355 devices although they consist of the same material type.
2. That the stability of 1K3A351 devices is difficult to predict through burn-in and life-test and that devices of this type may not be able to meet the relevant specifications in commercial production.

The following discussion is intended to address these issues and to make some recommendations for the processing of such devices.

The first topic to be considered is the differences between the two types of devices. In-house experience would suggest that devices consisting of similar material types should not differ radically from each other in long-term stability. The most significant difference between the two device types is their relative sizes. The 1K3A351 device is much larger that the 5K3A355 device. The respective bead sizes are:

1K3A351: 4.87mm bead diameter at base by 6.35mm bead length.

5K3A355: 2.54mm bead diameter at base by 3.50mm bead length.

It is generally accepted that the change in resistance value of thermistors during aging at elevated temperatures is due to a combination of different mechanisms. Some of these mechanisms relate to chemical changes in the bulk ceramic material, in particular in the composition of metal oxides in the material system. Other mechanisms relate to physical effects, such as stress relief in the crystal structure of the ceramic. This may take the form of the propagation of micro-cracks in the ceramic material and at the interface between the ceramic and metalization. Stress relief and chemical changes at the interface between the solder, used to attach the leads to the thermistor chip, and the metalization can also cause changes in device resistance. There can be some leaching of silver from the metalization to the solder. These various aging mechanisms do not continue indefinitely, the effects are accelerated at higher temperatures, and generally reach a maximum condition after a certain time.

Such effects are difficult to quantify, but can contribute to minor differences in aging characteristics for devices of different sizes consisting of similar material types. They are most likely to affect burn-in results as such aging effects associated with the solder interface generally happen in the early stages of a period of stress at high temperature.

In the particular situation being discussed here, it is unlikely that the aging effects outlined above have the most significant contribution to the difference in reported results. This is because of in-house experience and also because of the magnitude of the differences in the burn-in and 1000 hour life-test results and the similarity of results after 2000 hour life test for both component types. The 1000 hour life-test results are counter-intuitive for this device type, where it might be expected that the 1K3A351 device would have shown similar drift to the 5K3A355 device. It is likely that there is a more systematic source of variation in the reported results, and the following sections considers likely issues with measurement accuracy.

It is useful at this stage to represent the results in tabular form, showing the reported deviations in terms of percentages, in terms of resistance in Ohms and in terms of temperature in degrees Centigrade. It is also useful to state the relevant conversion factors for relating Resistance and temperature for this device type, 1K3A351, at 25 °C :

The sensitivity or Alpha value (% per °C ) = -4.39 (% / °C ) for this material type.

Temperature sensitivity for 1K3 device is -43.9 Ohms per °C.

1 Ohm is equivalent to 0.023 °C for 1K3 device.

1% change in resistance about 25 °C corresponds to a temperature change of 0.23°C.

1 Ohm corresponds to 0.1 % of the nominal value of 1000 Ohms at 25 °C.

| Summary Data for 1K3A351 devcie. | | | |
|---|---|---|---|
| **Test type** | **Mean Resistance Drift (% )** | **Mean Resistance Drift (Ohms)** | **Equivalent Temperature (°C)** |
| **Burn-in (168 hrs)** | 0.16 | 1.6 | 0.04 |
| **Life test (1000 hrs)** | 0.13 | 1.3 | 0.03 |
| **Life-test (2000 hrs)** | 0.47 | 4.7 | 0.11 |

| Summary Data for 5K3A355 devcie. | | | |
|---|---|---|---|
| Test type | Mean Resistance Drift (% ) | Mean Resistance Drift (Ohms) | Equivalent Temperature (°C) |
| Burn-in (168 hrs) | 0.07 | 3.5 | 0.02 |
| Life test (1000 hrs) | 0.26 | 13 | 0.06 |
| Life-test (2000 hrs) | 0.49 | 24.5 | 0.11 |

Based on some in-house experience with thermistor measurement, it was decided that there may be a systematic error associated with the measurement of the 1K3A351 device type, so the measurement system for such devices was evaluated. The particular focus was on the instrumentation used to measure resistance. The principal instrument type used in the measurement of the devices for the qualification evaluations was a PREMA 5001 multimeter.

The method of measurement used by such multimeters for resistance measurement of a component involves forcing a particular current through component and measuring the voltage induced across it. For thermistor components, the power dissipated during the resistance measurement can be an important consideration as it can result in "self-heating". This self-heating effect can cause the thermistor to heat up, with an associated decrease in resistance value, but the effect usually does not continue indefinitely in measurement situations as the component usually reaches thermal equilibrium with it's surroundings. This self-heating effect during measurement is more likely to occur in thermistor devices where the device construction is such that the thermal conductivity from the ceramic material to the surrounding medium is limited. It was considered that the 1K3A351 device may be prone to such self-heating effects, because of the large chip size and the amount of epoxy used to encapsulate it. Therefore the measuring system was evaluated to see if it could have contributed to the anomalies in the burn-in and life-test results.

The magnitude of the current in the component during measurement was considered. For the PREMA 5001 instrument, the current through the resistive element, for particular measurement ranges are outlined in the following table. For comparative purposes similar information is also included for a KEITHLEY 2000 type instrument.

| Specification for PREMA 5001 | | | Specification for KEITHLEY 2000 | |
|---|---|---|---|---|
| Measuring Range (Ohms) | Test Current in Device | | Measuring Range (Ohms) | Test Current in Device |
| 200 Ω, 2 kΩ | 0.7 mA | | 100 Ω, 1 kΩ | 1 mA |
| 20 kΩ | 70 uA | | 10 kΩ | 100 uA |
| 200 kΩ, 1.6 MΩ | 7 uA | | 100 kΩ, 1 MΩ | 10 uA |
| 16 MΩ | 0.7 uA | | 10 MΩ, 100 MΩ | 700 nA |

The measurement ranges of relevance for 1K3A351 devices at 25 °C are the 2 kΩ range and the 20 kΩ range. The measurement resolution required for 1K3A351 devices at 25 °C is +/- 0.1 Ω, which corresponds to a temperature of +/- 0.002 °C, and the resolution of both these ranges (and the 200 kΩ range) can provide this accuracy. The choice of range is not specified in the present processing instructions for such devices. The selection of resistance range used for measurement is somewhat arbitrary. The simplest case is where the meter is used in auto-ranging mode. In this mode, the control algorithm of the meter generally selects the lowest available range. However, it is also possible for the operator to select a measuring range. One issue with the selection of measuring ranges is that there is no specific indicator to show explicitly which range is active. This is the situation for the PREMA and KEITHLEY instruments. It is difficult for non-technical personnel to determine which range is active at a particular time.

It is generally the case that the choice of measuring range does not affect measurement accuracy of most thermistor components, but in reviewing the burn-in and life-test results from the qualification report, it was considered to be a possibility for 1K3A351 devices at 25 °C. To determine if this were the case, a series of measurements were made on sample 1K3A351 devices at 25 °C over the relevant measuring ranges. While the PREMA instrument was the most relevant, similar measurements were performed on a KEITHLEY for comparison purposes. The results are contained in the table at the end of this document.

The results show that the measuring range used has a significant effect on the measured resistance value. The most relevant effect is the difference in measured resistance value between the reading obtained on the 2 kΩ range and the 20 kΩ range of the PREMA meter. The results show that the measurements made on the 2 kΩ range are typically 1.2 Ohms, (0.1%) lower than those made on the 20 kΩ range, due to the self-heating of the thermistor associated with the larger current used on the 2 kΩ range. A similar trend is observed for the equivalent ranges on the KEITHLEY instrument, indicating that it is a fundamental feature of the device. From a technical perspective, the most accurate reading would be that obtained with the lower measuring current, that is the measurement made with self-heating effects minimized.

Similar evaluations were performed for 5KA3553 devices and for G2K7D110 devices. These did not show any significant differences between measurement ranges. It is likely that the construction of the 2K7 device in particular, which included a metal contact pad, provided good thermal contact between the thermistor and the medium, so that any heat generated due to self-heating during measurement would have been dissipated. The construction of the 5K3A355 device, and in particular the smaller chip size, and the smaller amount of epoxy required to encapsulate means that any heat dissipated in the ceramic chip by the measuring circuit can be transferred easily to the surrounding medium. The base resistance value of the 5K3A355 device is such that it will be measured on ranges where the current is low enough not to cause self – heating.

It is likely that anomalies noted in the results reported in the Qualification report for the 1K3A351 devices are due to the self-heating effect associated with the measurement current. For example, if the devices prior to burn-in were measured using the 2 kΩ range then the resistance readings would be approximately 0.1 % lower on average than they would have been using the 20 kΩ range. Then, if the measurements post burn-in were made using the 20 kΩ range the difference in values between pre burn-in and post burn-in would include the 0.1 % difference due to the self-heating effect in the initial measurements. This is a possible explanation for the differences in burn-in and 1000-hour life-test results for the1K3 and 5K3 devices, and the similarity in the 2000 hours life-test results.

**Conclusions:** Based on the discussion outlined in this document, it can be demonstrated that the measuring configuration of the instruments used for resistance measurement can affect the resistance value obtained for the 1K3A351 component. The effect can be of the order of 0.1%, 1.2 Ohms or 0.03 °C. The effect is due to the self-heating of the component due to the measuring current used by the meter. The most accurate resistance value is obtained when the magnitude of the measuring current is low enough not to cause appreciable self-heating of the component, while still giving the required resolution. For the 1K3A351 devices, 1 Ohm is equivalent to 0.023 °C, so that resistance measurement resolution of +/- 0.1 Ω, corresponding to 0.002 °C, is considered to be suitable. These measuring conditions can be satisfied using the 20 kΩ or 200 kΩ ranges on the PREMA 5001 meters, or using the 10 kΩ or 100 kΩ ranges on the Keithley 2000 series meter.

While the Burn-in and Life-Test measurements for the 1K3A351 devices documented in the Qualification Report were within the relevant specification limits, the effect of the measurement variation due to the ranging of the meter was a significant factor in the difference in results for 1K3A351 and 5K3A355 devices. To avoid such effects in general measurement of 1K3A351 devices, it is advisable to use a suitable range setting on the measuring instrument to limit power dissipation in the device. This point is developed further in the next section of this document.

**Recommendations:** Based on the discussion presented in this memo, the following recommendations should be implemented to maximize the accuracy of measurement of resistance of 1K3A351 in testing and in temperature sensing applications.

1. The manufacturing process instructions should be updated to specify which measuring range should be used for measurements at 25 °C for 1K3A351 devices. This should be the 20 kΩ range for PREMA 5001 meters and the 10 kΩ range for Keithley 2000 meters. As the set-up and identification of range settings on such meters is difficult for non-technical personnel, the instructions should specify that the instruments should be set up by technical personnel. Production operators should receive additional training in this area also.

2. The power dissipation in a resistive element is given by $\mathbf{P = I^2 * R}$ , where P is the power in Watts, I is the current in Amps and R is the resistance in Ohms. For the 1K3A351 device, measured with the 2 kΩ measuring range on the PREMA 5001 meter at 25 °C, the current in the device is 0.7 mA, or 0.0007 A. The power dissipated in the device is $(0.0007)^2 *(1000)$ Watts = 0.00049 Watts = 0.49 mW. At this power-level the self-heating effect causes resistance change of the order of 0.03°C, and it is likely that higher power dissipation would cause more significant temperature errors. The maximum power rating for this device type given in table 1(b) of ESA/SCC Detail Specification No 4006/013 is 2.0mW. The specifications should be reviewed and new maximum power ratings should be defined, based on practical evaluation.

| **1K3A351** | **Prema 5001** | | | | **Keithley 2000** | | | |
|---|---|---|---|---|---|---|---|---|
| Resistance (Ohms) measured at 25 Deg.C | | | | | Resistance (Ohms) measured at 25 Deg.C | | | |
| **Device ID (Serial No)** | 2 K-Ohm Range | 20 K-Ohm Range | 200 K-Ohm Range | Deviation (Ohms) 2K to 20 K Range | 1 K-Ohm Range | 10 K-Ohm Range | 100 K-Ohm Range | Deviation (Ohms) 1K to 10 K Range |
| 047 | 996.9 | 997.9 | 998.6 | 1.0 | 996.2 | 997.8 | 997.9 | 1.6 |
| 009 | 1001.6 | 1002.7 | 1003.4 | 1.1 | 1000.9 | 1002.5 | 1002.7 | 1.6 |
| 020 | 1000.6 | 1001.7 | 1002.0 | 1.1 | 999.8 | 1001.7 | 1001.9 | 1.9 |
| 062 | 1001.5 | 1002.7 | 1002.7 | 1.2 | 1000.8 | 1002.2 | 1002.5 | 1.4 |
| 029 | 999.8 | 1000.9 | 1001.9 | 1.1 | 999.0 | 1000.8 | 1000.9 | 1.8 |
| 071 | 1003.1 | 1004.2 | 1004.5 | 1.1 | 1002.9 | 1004.3 | 1004.4 | 1.4 |
| 036 | 1004.5 | 1005.7 | 1006.0 | 1.2 | 1004.2 | 1005.6 | 1005.8 | 1.4 |
| 019 | 1005.9 | 1007.3 | 1007.6 | 1.4 | 1005.6 | 1007.2 | 1007.4 | 1.6 |
| 016 | 1003.6 | 1005.1 | 1005.5 | 1.5 | 1003.0 | 1004.8 | 1004.8 | 1.8 |
| 025 | 1001.2 | 1002.3 | 1002.7 | 1.1 | 1000.7 | 1001.8 | 1001.9 | 1.1 |
| 046 | 999.1 | 1000.3 | 1000.8 | 1.2 | 998.7 | 1000.1 | 1000.4 | 1.4 |
| Average Deviation in measured value (Ohms) | | | | 1.2 | Average Deviation in measured value (Ohms) | | | 1.5 |
| Average Deviation in measured value (%) | | | | 0.1 | Average Deviation in measured value (%) | | | 0.2 |
| Average Deviation in measured value ($^{o}C$) | | | | 0.03 | Average Deviation in measured value ($^{o}C$) | | | 0.04 |