microbridge APPLICATION NOTE

Rejustor™ Power Guidelines

1 Introduction

The ***Rejustor*** is an adjustable resistor. The resistance is adjusted with pulsed heating current applied to the adjustment pins (ADJ) under control of *Rejust-it*, Microbridge Technologies' proprietary software.

Rejustor adjustment requires rapid heating, to very high temperatures, and rapid cooling. The ***Rejustor*** is manufactured to have high thermal isolation (from surrounding elements and the device substrate) and low thermal mass to allow rapid heating and cooling and adjustment within a short time span.

Power consumed within the resistor (as a result of applied voltage and current flow during normal operation) is dissipated as heat. A natural consequence of the thermal isolation of the device is that the device is subject to self-heating during normal operation as a resistor. The resistance of a Low-TCR ***Rejustor*** increases as the temperature of the thermally-isolated element increases. When the combination of (1) power dissipated in the ***Rejustor***, and (2) case (or package) ambient temperature is within the recommended limits, the resistance change due to self-heating is temporary. This change is observed as the self-heating coefficient of resistance. When power and temperature are above these limits, the resistance of the ***Rejustor*** may begin to drift permanently. The recommended limits for each ***Rejustor*** are specified in the datasheet.

Self-heating occurs when the power dissipated within the functional resistive element is sufficient to cause an instantaneous or sustained temperature rise in the ***Rejustor***. If the operating power is constant (doesn't vary widely) during operation, then the resulting self-heating induced resistance changes will be constant. When ***Rejustors*** are operating at constant power (for example, in a constant reference voltage or current), then the self-heating-induced resistance changes can be included in the adjustment (automatically compensated when the ***Rejustor*** is adjusted). In other words, self-heating induced resistance changes are compensated when the ***Rejustor*** is adjusted <u>at the operating power, provided that operating power is constant</u>.

This application note provides guidelines for ***Rejustor*** operation, both within the power limits specified in the datasheet and beyond. Because of the inter-dependence between power and temperature, this application note should be viewed with MB-APP21, ***Rejustor*** *Operating Guidelines for -55 to +125°C Operation.*

2 Power Considerations

All resistors generate heat as they dissipate power. The internal temperature of the resistive element in the ***Rejustor*** is a function of both power dissipation and environmental ambient (case) temperature. During the ***Rejustor*** adjustment process, the temperature required for short pulses to permanently change the resistance of the ***Rejustor*** is typically greater than 400°C.

Power dissipation during normal operation (as specified in the datasheet) can result in temporary changes to the resistance of the ***Rejustor***. The increase in internal temperature of the ***Rejustor*** due

---

™ ***Rejustor*** is a trademark of Microbridge Technologies to self-heating during normal operation is insufficient to cause a permanent change to the resistance of the ***Rejustor***. In cases where the ***Rejustor*** is adjusted in-circuit under normal (relatively constant) load, self-heating is compensated as part of the adjustment process and is therefore not a source of calibration or adjustment error.

Excursions of power and temperature beyond recommended limits may first result in resistance excursions from the adjusted resistance value (due to natural temperature coefficient effects within the material) and secondly, at higher power/temperatures permanent change to the resistance of the ***Rejustor***. The extent of any permanent changes that may occur depends on the length of time and magnitude of the excursions. The limits listed in the datasheet are conservatively intended to avoid the first TCR-based resistance excursions, so will likewise prohibit any permanent excursion effects. Drift specified in the datasheet is a result of accelerated life testing un-powered at 150℃ where after 1000hours testing, drift plateaus at 0.5% increase from the original resistance value.

2.1 Rated Power

Rated power for ***Rejustors*** is not the same as maximum power. ***Rejustors*** can operate above the rated power without damage, but will experience greater self-heating according to the self-heating coefficient of resistance. ***Rejustors*** may be operated beyond maximum power. However it is not recommended that ***Rejustors*** operate beyond maximum power for sustained periods.

Operation beyond rated power increases internal self-heating beyond ~5℃, at which temperature stability and performance parameters have been verified. When the combination of internal self-heating and operating temperature exceed 130℃ (to allow operation at rated power and 125℃ case temperature), the rate at which the resistance drifts will increase. Note that all resistors (including ***Rejustors***) drift by small but non-zero amounts and the rate at which this occurs is dependant upon the resistor’s internal temperature.

Rated power varies by product and is dependent upon internal geometries required to attain the specific resistance value. There are three families of Low-TCR ***Rejustors***: The MBD-xxx-xS standard family of dual discrete ***Rejustors*** is nominal rated at 2mW total for the pair of ***Rejustors*** (1mW each for a 1:1 ratio). The MBD-xxx-xL family of low-power dual devices is nominally rated for 1mW dissipation between both devices. Standard power products are available in 8-pin SOIC and 16-pin QFN. The Low-power devices are only available in space-saving 16-pin QFN packages. Both families are offered in a variety of resistance values and ratios (the ratio of resistance values between two ***Rejustors*** in a package). Single ***Rejustors*** are rated at 0.5mW and are available in 16-pin QFN packages.

Design tolerance should be sufficient so that maximum power is not exceeded over the entire anticipated adjustment range (typically the minimum adjustable resistance for the ***Rejustor***).

3 Self Heating – Low TCR Rejustors

Self-heating causes a temporary fractional resistance change (in ppm), defined as:

$$\frac{\Delta R_{self-heating}}{R}$$

The "Self-Heating Coefficient of Resistance" (SHCR) is defined as fractional resistance change per mW of power dissipated in the ***Rejustor***, defined as:

$$SHCR = \frac{\Delta R_{self-heating}}{R} \Big/ P(mw)$$

The Self-Heating Coefficient of Resistance increases somewhat as the resistance of the ***Rejustor*** are adjusted. The SHCR values in Microbridge datasheets represent the maximum experienced over the adjustment range.

3.1 Self-Heating Example

Consider an example where 1.4V is applied across an MBD-103-AS ***Rejustor*** that has been adjusted down 30% to 7KΩ. This corresponds to 0.28mW dissipated in the ***Rejustor***. Given the self-heating coefficient of the unadjusted ***Rejustor*** (MBD-103-AS) is 2000ppm/mW, then the resistance change due to self-heating is shown below:

$$\begin{aligned}\Delta R_{self-heating} &= R \times SHCR \times P \\ &= 7K\Omega \times 2000\,ppm/mW \times 0.28mW \\ &= 3.9\Omega\end{aligned}$$

The change in resistance as a result of self-heating represents <0.6% of the overall resistance of the ***Rejustor***.

3.2 Relative Self Heating

The Relative Self-Heating Coefficient of Resistance (RSHCR) represents the difference between the two temporary fractional resistance changes due to self-heating, *per mW dissipated in the pair of **Rejustors***. It applies to two ***Rejustors*** used together and is most relevant when the ***Rejustors*** operate as a divider. Relative self-heating is zero when both ***Rejustors*** are equal, that is, both have the same SHCR, and both are either unadjusted or adjusted by the same amount.

The relative self-heating effect is present if the two ***Rejustors*** have different adjusted states or different as-manufactured resistance (as is the case for ratio ***Rejustors***). RSHCR tends to a maximum when one ***Rejustor*** is not adjusted while the other is adjusted down to its full extent (e.g. 30% down).

In practice, the RSHCR depends sensitively on the real combination of values of SHCR's and resistances.

3.2.1 Some illustrative examples:

The following examples provide more familiarity into the behavior of RSHCR. In general, these examples confirm that relative self heating is low for two ***Rejustors*** carrying the same current.

3.2.1.1 Example 1, Two Unadjusted Rejustors

Consider a pair of nominally-equal-valued, un-adjusted ***Rejustors***, which also have the same SHCR's (i.e. $SHCR_1$ = $SHCR_2$, in ppm/mW). If this pair of ***Rejustors*** is connected in a voltage divider configuration (carrying the same current), then the self-heating-induced resistance changes (in ohms) would be the same (i.e. $\Delta R1_{self\text{-}heating} = \Delta R2_{self\text{-}heating}$), and *<u>the relative (ratiometric) resistance changes would be zero</u>*, regardless of the absolute value of the SHCR's (as long as the two SHCR's are the same).

$$\frac{\Delta R1_{self-heating}}{R1} = \frac{\Delta R2_{self-heating}}{R2}$$

Equivalently, for unadjusted ***Rejustors*** with equal SHCR and equal current,

$$\frac{R1 + \Delta R1_{selfHeating}}{R2 + \Delta R2_{selfHeating}} = \frac{R1}{R2}$$

3.2.1.2 Example 2, Two Equally Adjusted Rejustors

Consider the same pair of ***Rejustors*** as in Example 1, in the same configuration, but now they are both adjusted to the same state (adjusted by the same fraction). Again, the SHCR's will be the same, and the self-heating-induced resistance changes (in ohms) would be the same (i.e. $\Delta R1_{\text{self-heating}} = \Delta R2_{\text{self-heating}}$), and *the relative (ratiometric) resistance changes would be zero*, regardless of the absolute value of the SHCR's (as long as the two SHCR's are the same).

3.2.1.3 Example 3, Two Rejustors with Equal SHCR and Unequal as-manufactured Resistance

Consider a pair of nominally **un**equal-valued ***Rejustors***, in a divider configuration (carrying the same current), having the same adjusted state (i.e. both un-adjusted, or both adjusted by the same fraction), and having the same SHCR's (in ppm/mW), (i.e. $SHCR_1 = SHCR_2$), for example the MBD-472-CL, where R2=5xR1. The self-heating-induced resistance changes (in ohms) will be *proportional to their respective resistance values*, and also proportional to the power dissipated in each resistor. Note that if the current is the same, the dissipated power will be different.

$$\Delta R1_{self-heating} = SHCR1 \times R1 \times P1$$
$$\Delta R2_{self-heating} = SHCR2 \times R2 \times P2$$

For the example of the MBD-472-CL, R2 = 5xR1, therefore P2 = 5xP1 if the two ***Rejustors*** carry the same current. Therefore,

$$\Delta R2_{self-heating} = 25 \times \Delta R1_{self-heating}$$

Furthermore,

$$\frac{\Delta R1_{selfHeating}}{R1} = \frac{5 \times \Delta R2_{selfHeating}}{R2}$$

Typically, for pairs of ***Rejustors*** having the same SHCR but unequal nominal resistance,

$$\frac{R1 + \Delta R1_{selfHeating}}{R2 + \Delta R2_{selfHeating}} \neq \frac{R1}{R2}$$

3.2.1.4 Example 4, Two Rejustors with Unequally Adjusted Resistance

In general, a pair of nominally-equal-valued ***Rejustors***, having same SHCR in their unadjusted states, will tend to have maximum RSHCR when one of the ***Rejustors*** is unadjusted while the other is adjusted to its full extent (e.g. 30%-down). The RSHCR provides an indication as to the difference in self-heating induced fractional resistance changes for an adjusted ***Rejustor*** versus an unadjusted ***Rejustor***.

Consider a pair of nominal 10kohm ***Rejustors*** in a divider, carrying the same current. Typically in a divider the resistors carry the same current. If both ***Rejustors*** are un-adjusted, then the two ***Rejustors*** will experience equal initial self-heating induced resistance changes (whose magnitude will vary depending on the applied voltage or current). This was described in Example 1 (Section 3.2.1.1).

Next assume one of the ***Rejustors*** is adjusted down 30% (to 7kohm), while the other remains unadjusted. For convenience, assume that the power dissipated in the adjusted ***Rejustor*** (R1) remains the same as in the earlier example treating absolute SHCR (Section 3.1). In this case, the current through the divider will be 0.2mA.

Knowing that the SHCR data provided in the datasheet represents the worst-case and that worst-case occurs for a ***Rejustor*** that has been adjusted down 30%, we can use RSHCR to find the self-heating induced change in the unadjusted ***Rejustor***.

In order to determine the resistance in the unadjusted resistor (ΔR1), we need to consider the Relative Self Heating Coefficient of Resistance, which is provided in the datasheet. For unequally adjusted ***Rejustors*** operating at equal current, the following applies:

$$RSHCR \times \left(P_{R1} + P_{R2}\right) = \frac{\Delta R1}{R1} - \frac{\Delta R2}{R2}$$

Given 0.2mA through the divider, in this example, calculate power dissipated in each ***Rejustor***. The unadjusted ***Rejustor*** (R1) dissipates 0.4mW, and the adjusted ***Rejustor*** (R2) dissipates 0.28mW. ΔR2 can be calculated from the SHCR:

$$\begin{aligned}\Delta R2_{self-heating} &= R2 \times SHCR \times P \\ &= 7K\Omega \times 2000\, ppm/mW \times 0.28mW \\ &= 3.9\Omega\end{aligned}$$

In this example we need to find ΔR1. The RSHCR equation can be rearranged as:

$$\Delta R1 = R1 \times \left(RSHCR \times \left(P_{R1} + P_{R2}\right) + \frac{\Delta R2}{R2} \right)$$

$$\Delta R1 = 10{,}000 \times \left(240\, {}^{ppm}\!/_{mW} \times \left(0.4mW + 0.28mW\right) + \frac{3.9\Omega}{7000\Omega} \right)$$

$$\Delta R1 = 7.2\Omega$$

Note that,

$$\frac{R1 + \Delta R1_{selfHeating}}{R2 + \Delta R2_{selfHeating}} = \frac{10K\Omega + 7.2\Omega}{7K\Omega + 3.9\Omega} \neq \frac{R1}{R2}$$

There is negligible observable impact on the output voltage of the divider as a result of SHCR and RSHCR. The current through R1 causes a temporary increase of 7.2Ω and a temporary resistance increase in R2 of 3.9Ω. The difference between these resistance changes would be observed as a difference from the expected voltage. The expected (ideal) voltage for this example would be:

$$V_{out} = \frac{2V \times 7k\Omega}{10k\Omega + 7k\Omega}$$

$$= 0.82353V$$

Taking self-heating into account, the observed voltage would be:

$$V_{out} = \frac{2V \times \left(7k\Omega + 3.9\Omega\right)}{\left(10k\Omega + 7.2\Omega\right) + \left(7k\Omega + 3.9\Omega\right)}$$

$$=0.82345V$$

The self-heating induced difference in resistance in this example accounts for <80μV. This 0.01% deviation in the output voltage of the divider can be attributed to the relative self heating coefficient of resistance.

3.3 In-circuit Calibration Provides Self-Heating Compensation

Self-heating induced resistance change is automatically compensated during in-circuit calibration in many applications. In-circuit calibration adjusts the resistance of the ***Rejustors*** to achieve the required target value of the circuit output parameter. The target may be voltage or offset, etc. The absolute value of the resistance of the ***Rejustors*** is not important in these cases, what is important is the performance of the circuit.

The advantage of in-circuit calibration is that the circuit is in its normal operating mode, at its normal operating power so the self-heating induced changes to the resistance are already present. Furthermore, only the output value of the overall circuit is important, not the ohmic value of the ***Rejustor***. If, after calibration, the resistance of the ***Rejustor*** was measured (at a lower power), the observed value may appear low. Even though the measured value may appear low (recall self-heating increases resistance), the operating value is still correct for the circuit at nominal operating conditions.

3.4 Non-constant Power

In-circuit calibration will correct for ***Rejustor*** self-heating effects when the ***Rejustor*** operates at constant or nearly constant power. In the case of non-constant power, the ***Rejustor*** internal temperature will change as its power changes -- causing resistance changes. For example, consider an application where an MBS-472-AL ***Rejustor*** is connected to a sensor with an output voltage range from 0.4V and 2.0V. The adjusted value of the ***Rejustor*** is 4.1kohms. What is the relative difference in the resistance as a result of the voltage variation?

The MBS-472-AL has SHCR 4000ppm/mW. At 0.4V, the power is:

$$P = \frac{V^2}{R}$$

$$= \frac{(0.4V)^2}{4100\Omega}$$

$$P = 39\mu W$$

well below the rated 1mW. At this power, Delta-R will be:

$$\begin{aligned} \Delta R_{self-heating} &= R \times SHCR \times P \\ &= 4100\Omega \times 4000\, ppm/mW \times 0.039mW \\ &= 0.6\Omega \end{aligned}$$

The actual instantaneous resistance will be 4100.6Ω.

At 2.0V, the power is 976μW, and Delta-R will be:

$$\begin{aligned} \Delta R_{self-heating} &= R \times SHCR \times P \\ &= 4100\Omega \times 4000\, ppm/mW \times 0.976mW \\ &= 16.0\Omega \end{aligned}$$

The difference between these two resistances is 15.4Ω, or <0.4% of the 4100Ω adjusted resistance, at the two voltage extremes.

3.4.1 Rejustor Dividers in Non-constant Power Applications

Much of the literature produced by Microbridge recommends using ***Rejustor*** dividers to enhance performance. Likewise, using a ***Rejustor*** divider decreases the difference in output voltage for systems that operate at a different power from the power level at which they were adjusted or for systems working under non-constant power.

This example uses an MBD-103-BS with R1 adjusted to 9500Ω, and R2 adjusted to 15KΩ. Since the SHCR in the datasheet represents the worst-case value corresponding to a maximally adjusted ***Rejustor***, we will use SHCR to calculate the self-heating induced resistance change in R2, and then apply RSHCR to calculate the resistance change in R1. The circuit is shown in figure 2.

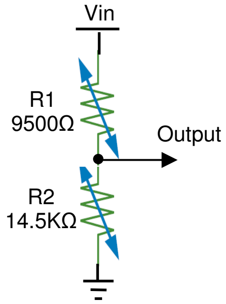


Figure 1: Non-constant power in divider

Assume the input voltage varies from 0.4V to 5.0V. This provides current through the divider at 16.6µA and 208µA respectively.

Calculate power for each ***Rejustor***:

$$P_{R1-low} = 16.6\mu A^2 \times 9500\Omega$$

$$= 0.003\text{mW}$$

$$P_{R1-high} = 208\mu A^2 \times 9500\Omega$$

$$= 0.412\text{mW}$$

Similarly,

$$P_{R2-low} = 16.6\mu A^2 \times 14{,}500\Omega$$

$$= 0.004\text{mW}$$

$$P_{R2-high} = 208\mu A^2 \times 14{,}500\Omega$$

$$= 0.627\text{mW}$$

The change in self-heating induced resistance of R2 (the more adjusted of the two) from one voltage extreme to the other is calculated using SHCR:

$$\Delta R2_{low} = R2 \times SHCR \times P$$

$$= 14.5K\Omega \times 1800 \frac{ppm}{mW} \times 0.004mW$$

$$= 0.104\Omega$$

$$\Delta R2_{high} = R2 \times SHCR \times P$$

$$= 14.5K\Omega \times 1800 \frac{ppm}{mW} \times 0.627mW$$

$$= 16.4\Omega$$

The change in self-heating induced resistance for R1 is calculated from RSHCR

$$\Delta R1_{low} = R1 \times \left(RSHCR \times (P_{R1} + P_{R2}) + \frac{\Delta R2_{low}}{R2} \right)$$

$$\Delta R1_{low} = 9{,}500 \times \left(600 \, {}^{ppm}\!/_{mW} \times (0.0026mW + 0.004mW) + \frac{0.104\Omega}{14{,}500\Omega} \right)$$

$$\Delta \text{R1}_{\text{low}} = 0.106\Omega$$

And,

$$\Delta R1_{high} = R1 \times \left(RSHCR \times \left(P_{R1} + P_{R2}\right) + \frac{\Delta R2_{high}}{R2} \right)$$

$$\Delta R1_{high} = 9{,}500 \times \left(600 \,{}^{ppm}\!/_{mW} \times \left(0.412mW + 0.627mW\right) + \frac{16.4\Omega}{14{,}500\Omega} \right)$$

$$\Delta \mathrm{R1}_{\mathrm{high}} = 16.7\Omega$$

We're interested in learning by how much the output voltage will vary as a function of self-heating induced resistance changes in the ***Rejustors***. To do this, we examine the ratio between the resistances of two ***Rejustors*** at low and high voltage (power).

Low,

$$\Delta = \frac{R1 + \Delta R1}{R2 + \Delta R2}$$

$$= \frac{9500\Omega + 0.106\Omega}{14500\Omega + 0.104\Omega}$$

$$= 0.6552$$

High,

$$\Delta = \frac{R1 + \Delta R1}{R2 + \Delta R2}$$

$$= \frac{9500\Omega + 16.7\Omega}{14500\Omega + 16.4\Omega}$$

$$= 0.6556$$

The difference between these ratios at low and high power is <0.06%, substantially better than when a single ***Rejustor*** was used.

4 Drift-Stability

Drift stability is a function of external temperature, applied power and time. Drift is defined as a permanent change in resistance. That is, after the ***Rejustor*** is subject to high power or temperature, or both, when the power is reduced and temperature returns to ambient (or room), the resistance change is still present. In this way it is different from self-heating coefficient of resistance, where the resistance change is temporary. Any ***Rejustor*** resistance drift is superimposed upon transient temperature changes due to self-heating.

Rejustor drift is measured under normal operating conditions at less than +0.5% based on un-powered accelerated life testing at 150℃ for 1000hours (temperature stress).

High-temperature operation increases the rate of resistance drift and high-temperature can be a function of increased power (which increases internal temperature) or ambient temperature or both.

The same 0.5% resistance change has been observed for standard parts operating carrying 5mW (five-times rated power) at 125℃ for 1000hours. This is consistent with the local temperature at the ***Rejustor*** element being elevated to approximately 150℃.

Aside from temporary resistance changes due to self-heating, at these elevated ambient temperatures, and/or above rated power, the ***Rejustor's*** local temperature is approaching the temperatures used for long-term ageing tests (e.g. 150℃, 175℃). For example, if standard-power ***Rejustors*** are operated at 125℃ with 5mW (5x rated power), then the internal temperature will be about 125+25=150℃ instead of about 125+5=130℃.

It should be noted that accelerated life testing shows approximately 60% of the drift occurs within the first 100 hours. That is, after 100 hours the resistance of the ***Rejustor*** has drifted 60% of the way to the value observed after 1000hrs when operating within rated power and temperature.

Measured drift is always in the direction of increasing resistance. This determinism provides several options for overall resistance management. For example, knowing drift will be positive allows users to intentionally adjust the resistance of the ***Rejustor*** slightly low knowing it will drift to closer to target with time, or to introduce a burn-in cycle following final adjustment to reduce subsequent drift even lower.

4.1 Power Derating

The ***Rejustor*** can operate at higher temperature and maintain drift specifications if the power is derated. A sample power derating curve is shown in Figure 2 below. The ***Rejustor*** can be operated at rated power to a case temperature of 125°C, after which power must be decreased, reaching 0mW at 130°C. Maintaining power and temperature within these bounds will maintain drift stability as specified in the datasheet.

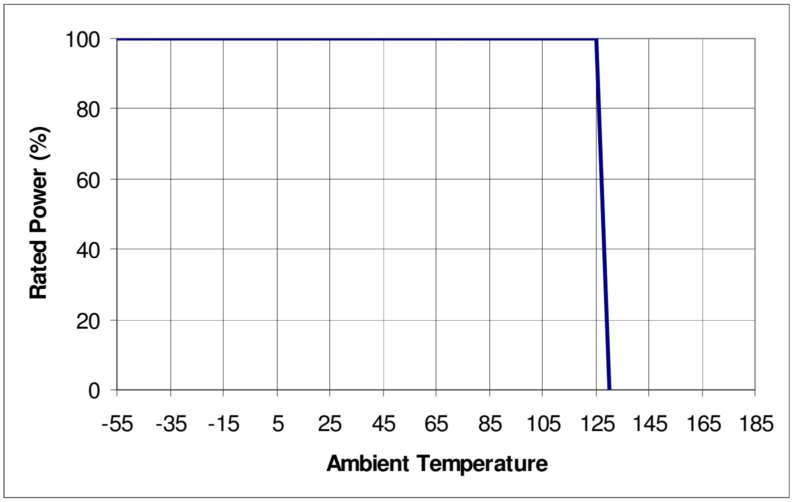
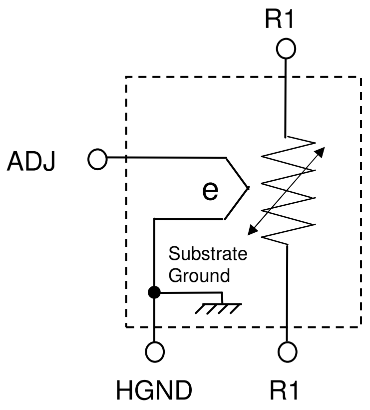


Figure 2: Power Derating to Maintain Drift Specification in datasheet

5 Overvoltage

Maximum rated voltage is specified at 25V. Standard ***Rejustors*** will exceed maximum power rating before hitting this limit; therefore it is of little concern for most applications.

The resistive element and heating element are electrically isolated within the device and the substrate is floating. Care must be taken to ensure the voltage drop between any pair of pins (for instance the resistor and HGND) doesn't exceed 25V. For example, the resistive element of the ***Rejustor*** could be used on a 48V supply on the condition that HGND is electrically isolated from the system ground. Otherwise the overvoltage condition will cause damage to the ***Rejustor***.



Overvoltage Spec:
No more than 25V
between any two pins

Figure 3: Overvoltage Spec Illustration

6 Summary

Rejustors are micro-power devices manufactured with low thermal mass and high thermal isolation, making them susceptible to internal heating as they dissipate power. When operating within rated power (as specified in the datasheet), internal heating is <5°C. Beyond rated power, ***Rejustors*** exhibit an increased resistance due to self-heating (SHCR). Increased power, for example 5x rated power, and high operating temperature increase the rate of drift.

The self-heating coefficient of resistance (SHCR) provided in the datasheet is used to calculate the resistance increase as a result of applied power. This temporary resistance change is generally low (<0.5%) at rated power. Adjusting one ***Rejustor*** relative to the other in a divider causes a relative resistance mismatch due to self-heating. The example in this application note shows the mismatch at 0.01%.

When the ***Rejustors*** are calibrated at the typical operating power, self-heating is included in the compensated resistance and will not impact the circuit. When the ***Rejustors*** are operating at non-constant power the SHCR and RSHCR should be considered in predicting circuit performance. Using a divider configuration provides an order-of-magnitude reduction in the effect of self-heating induced resistance changes to the output.

Drift is rated at +0.5% based on accelerated life testing at 150°C for 1000hours. Higher power and or higher operating temperatures will accelerate the rate at which the resistance drifts to this value. Internal power dissipation and ambient or case temperature are independent, but directly related to this drift. Power can be increased if external temperature is decreased to maintain an internal temperature of 130°C or lower, thereby maintaining performance as specified in the datasheet.